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ASSESSMENT OF ALTERNATIVES FOR UPGRADING NAVY SOLID WASTE DISPO--ETC(U)

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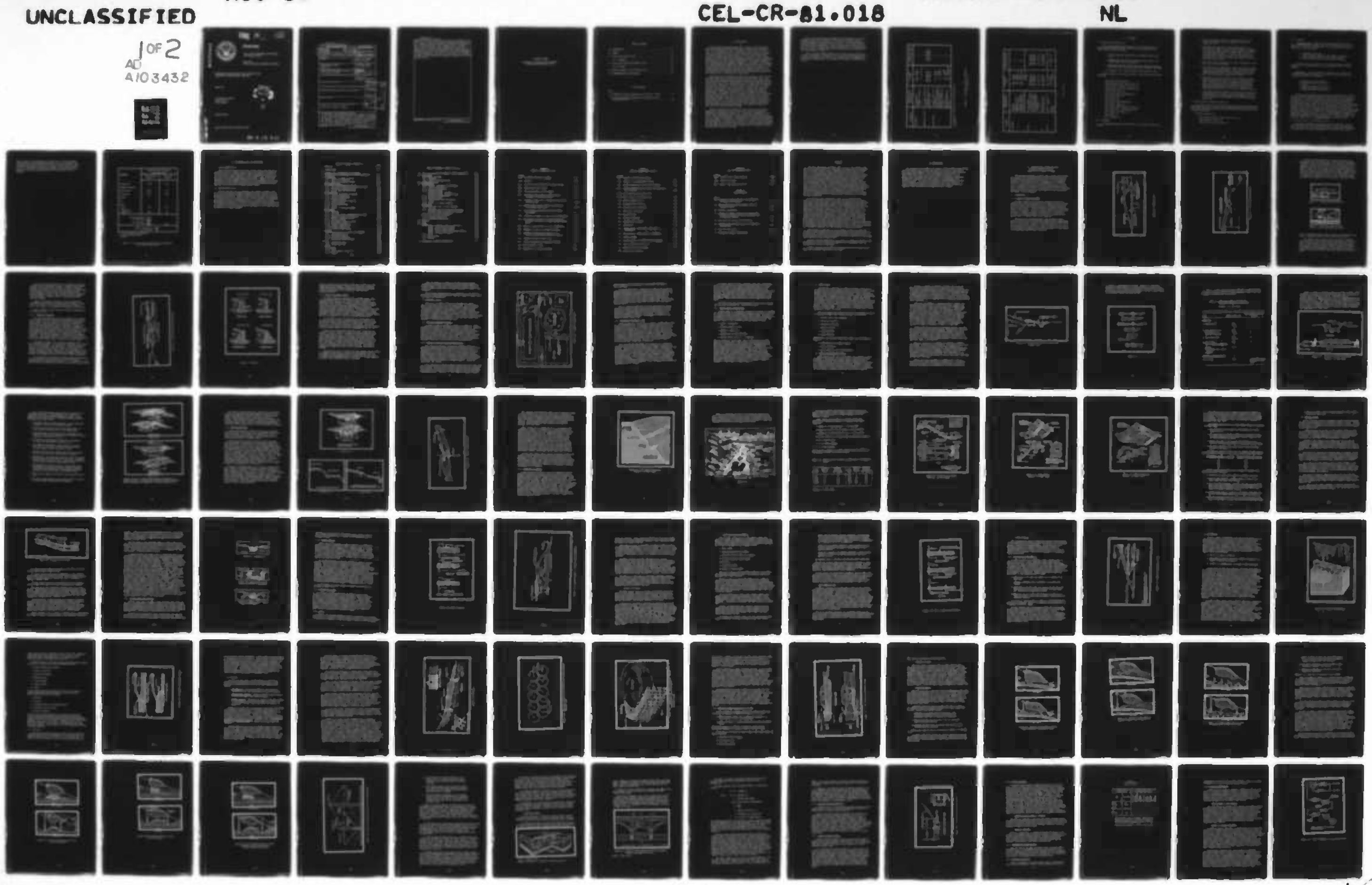

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

ASSESSMENT OF ALTERNATIVES FOR UPGRADING NAVY SOLID WASTE DISPOSAL SITES, VOLUME 2

August 1981

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An Investigation Conduct by
JRB Associates, Inc.
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The Naval Civil Engineering Laboratory as part of the NAVFAC Solid waste R&D Program performed an assessment for upgrading Navy solid waste disposal sites. The purpose of this effort was threefold: (1) to determined the extent of this effort the Navy may have to modify its current solid waste disposal practices to enable compliance with RCRA, (2) define the

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technological concepts that represent upgrading techniques, and (3) to identify research priorities concerning the technologies for solid waste disposal. This document consists of three volumes. This volume (2) provides a compilation of available technological alternatives for upgrading Navy disposal sites to comply with the criteria and associated costs for implementation of these technologies. The results of this effort are intended to assist engineering field divisions and public works personnel in identifying cost effective technology to upgrade existing land disposal sites.

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EXECUTIVE SUMMARY

ASSESSMENT OF ALTERNATIVES FOR UPGRADING NAVY SOLID WASTE DISPOSAL SITES

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1.0 INTRODUCTION

The Civil Engineering Laboratory (CEL), as part of the NAVFAC Solid Waste R&D Program, performed an assessment of alternatives for upgrading Navy solid waste disposal sites. The purpose of this effort was three fold: (1) to determine the extent the Navy may have to modify its current solid waste disposal practices to enable compliance with Section 4004 of the Resource Conservation and Recovery Act; (2) to define technological concepts that represent effective upgrading techniques; and (3) to identify research priorities concerning the technologies for solid waste disposal that are aligned with the Navy's need to maintain its land disposal capability while minimizing cost and manpower requirements. The results of this effort will assist Engineering Field Division (EFD) and Public Works (PW) personnel in characterizing the problems facing their facilities with regards to continued on-base disposal operations, identifying areas of concern in the development of new facilities in wetland and non-wetland areas, and to provide information on the methods and cost of upgrading and/or developing new and existing sites to comply with new regulations.

This effort, under the guidance of CEL, was performed by JRB Associates and EMCON Associates. The work was divided into three major tasks. The first task was the identification and definition of potential environmental and operational problems in land disposal of solid waste aboard Navy installations that relate to the implementation of the Federal landfill classification criteria (40 CFR 257). The work involved the compilation of existing information on Navy disposal sites as well as 15 field visits to gather specific, missing data. The second task was to identify and assess Navy application of technological alternatives for resolving the potential problem areas. This effort involved a review of remedial technological alternatives and associated costs for upgrading disposal sites in accordance with the Federal criteria. The third task was to evaluate the siting and operational procedures required for the development of future Navy solid waste disposal sites. This was accomplished by utilizing the information gathered from the 15 field visits to active on-base disposal sites plus an additional three visits to Naval bases situated in wetlands environments (but not necessarily operating landfills). The document prepared from this effort was divided into three volumes.

Volume 1 identified the "Criteria for Classification of Solid Waste Disposal Facilities and Practices," 40 CFR 257. The eight categories addressed in the Federal regulation were: floodplains, endangered species, surface water, groundwater, disease, air, safety and land spreading. In order to assist field personnel in assessing these categories and identifying areas of possible noncompliance, a "decision tree" flow diagram was developed for each category. The decision tree consists of a series of questions that, when answered about a specific site, determine if remedial action is required. The last segment of this volume identifies the siting and operational requirements for constructing new solid waste disposal sites in wetlands and other environmentally sensitive locations.

Volume 2 of this document is intended to provide guidance to landfill designers and operators in selecting the most cost effective remedial technology based on an assessment of site specific conditions identified using the decision tree guide provided in Volume 1. This volume presents available remedial technologies, as well as avante-garde concepts that may be utilized in bringing Navy solid waste disposal sites into compliance with Federal criteria. A summation of these technologies and their associated costs are presented in Table 1-1.

Volume 3 of this document summarizes the observations and findings of the study, identifies the potential areas of criteria noncompliance within the Navy, and presents an estimate of the economic impact of upgrading the 39 known Navy disposal sites. The results of this effort are summarized in Chapter 2.

CRITERION	REMEDIAL ACTION ALTERNATIVES	UNIT CAPITAL COST*	AVERAGE O&M COSTS (% of Capital Cost)
Floodplains	Perimeter Berms	$230 - 350/yd	3
	Floodwalls	350 - 600/yd	4
	Control of Backwater Flow	7K - 30K total	9
Endangered Species	Protecting Endangered Species	Site Specific	Site Specific
	Selective Landfilling	Site Specific	Site Specific
	Mitigation Land	Site Specific	Site Specific
Surface Water	Ditches, Diversions, Waterways	15 - 20/yd	6
	Terraces and Benches	5 - 9/yd	5
	Chutes and Downdrains	90/yd	5
	Drainage System	40 - 630/yd	4
	Grading and Revegetation	3 - 8/yd^2	3
	Surface Capping	10 - 30/yd^2	5
	Sedimentation Ponds	8K - 11K/acre ft	4
	Liners	27K - 70K/acre	5

* cost without engineering or contingency costs.
K = $1000

TABLE 1-1 Alternative Landfill Technologies and Associated Costs

CRITERON	REMEDIAL ACTION ALTERNATIVES	UNIT CAPITAL COST*	AVERAGE O&M COSTS (% of Capital Cost)
Groundwater	Trenches	$300 - 5K/yd	2
	Grouting	6K - 11K/yd	2
	Subsurface Drains	530 - 700/yd	
	Exraction Wells	25 - 50/vert. ft	6
	Leachate Collection	25 - 30/yd	4
	Leachate Treatment	20K - 500K total	15
	Leachate Attenuation	230 - 325/yd	6
	Groundwater Monitoring	75/vert. yd +3K/well	$400/sample + 1%/well
Disease	Sewage Sludge - Septic Tank Pumping	Site Specific	Site Specific
	Controlling Vectors	Site Specific	Site Specific
	Controlling Rodents	Site Specific	Site Specific
	Controlling Mosquitos	Site Specific	Site Specific
	Controlling Health Hazards	Site Specific	Site Specific
Air	Controlling Fires	Site Specific	Site Specific
	Controlling Dust	Site Specific	Site Specific
Safety	Gases - Well Probes	4.2K - 4.7K/acre	$700/sample + 1%/well
	Vents	400 - 600	9
	Fires	Site Specific	Site Specific
	Birds	32K/acre	4
	Access	30/yd + 2.5K	4

Table 1-1 cont'd.

2.0 SUMMARY

2.1 Active Navy Disposal Sites

This section presents the findings of the study based upon the 15 active on-base landfills visited. Selection of these facilities was based upon the following criteria:

- selected disposal sites must be representative of all Navy sites
- geographical areas (North, South and Central regions of the United States) must be represented
- some sites should be located within the Standard Metropolitan Statistical Area where the Navy has been designated lead agency
- operating life of the site should be greater than 3 years

From the possible active on-base landfills, CEL selected the following facilities:

Naval Base, Great Lakes, IL
Naval Weapons Support Center, Crane, IN
Marine Corps Air Station, Quantico, VA
Naval Ordnance Station, Indian Head, MD
NAS Patuxent River, MD
Marine Corps Base, Camp LeJeune, NC
NAS, Whiting Field, FL
NAS, Mayport, FL
NAS, Ocean, Virginia Beach, VA
NAS, Moffett Field, CA
Mare Island, Naval Shipyard, Vallejo, CA
Marine Corps Base, Camp Pendleton, CA
NAS, Miramar, San Diego, CA
NAS, Fallon, NV
NAS, Oak Harbor, WA

2.1.1. Findings

The general observations and findings from the sites visited are as follows:

- Most Navy disposal sites were in good condition and would require only a minor amount of upgrading to comply with RCRA Section 4004.

- A number of the sites were receiving wastes which are on EPA's hazardous waste list; most notably asbestos. Although the Navy has a need to dispose of large quantities of asbestos, this waste material needs to be either taken off site by a certified disposal operator or the Navy needs to apply for individual State permits for disposal of this waste. This has been done on at least one base, and therefore, may be the preferred course of action.

- Most of the disposal operations are small, averaging less than 50 tons per day of solid waste.

- A few sites had waste quantities in excess of 100 TPD, composed mostly of paper and putrescibles. These sites would be likely candidates for alternate disposal technology when costs for upgrading current landfill sites and developing new landfill sites to comply with the criteria are considered.

- The majority (11) of the sites may have a potential problem meeting the groundwater criteria. This is especially true in areas with medium to high soil permeability and high water table, such as the East coast. Groundwater compliance may prove to be the most serious problem facing these landfills. Monitoring programs would be most useful in accessing any adverse impacts these sites may have on the underlying aquifers.

- A potential problem area common to a number of Naval landfills is compliance with the safety criteria, expecially site access and gas generation. Remedial actions would require enclosure of the facilities and establishment of gas monitoring programs, respectively.

2.2 Future Navy Solid Waste Disposal Sites

This section summarizes the findings relative to the Federal requirements concerning the siting of new solid waste disposal facilities at Naval installations. This task required visits to three additional Naval bases situated in a wetlands environment.

The bases selected were:

Naval Amphibious Base, Little Creek, Norfolk, VA

Naval Shipyard, Norfolk, VA

Naval Air Station, New Orleans, LA

2.2.1 Findings

Non-Wetland Areas. Based on the information obtained from the 15 active on-base disposal sites and a review of the Federal criteria it was found that the Navy will generally have to do the following to locate a landfill in a non-wetland area:

- groundwater monitoring
- obtain NPDES and Dredge and Fill Permits (as required)
- install leachate collection and treatment systems
- ensure the isolation of the refuse from groundwater

Construction of a new landfill in a non-wetland area will increase disposal costs by approximately 50% to an estimated $12.00 per ton for disposal.

Wetland Area. From the information gathered at the 3 Naval bases located in a wetlands environment, the following items for constructing a landfill will have to be considered:

- depression of the watertable
- detailed groundwater monitoring
- levees
- leachate treatment and collection
- hydrologic diversion systems
- NPDES and Dredge and Fill Permits

The fact that many Naval installations are located in areas of the U.S. that are typified by wetlands topography presents the Navy with the unique and more difficult problem of disposing of solid waste in an environmentally suitable area. In order to comply with both the Executive and DOD orders on wetland protection, the Navy must evaluate all potential alternatives for solid waste disposal from both the economic and environmental perspectives. Should a Naval activity decide to pursue land-disposal in a wetlands it must be prepared to face a long, difficult, and expensive permitting process and possible legal action. Upon completion of this phase of the development process, the Naval activity must be prepared for the considerable expense of engineering and constructing the actual site. The technologies commonly associated with abating the environmental problems posed by construction of a landfill in a wetland are expensive to design and implement. A conservative estimate for disposal of solid waste in a "wetlands landfill" is $30.00 per ton.

2.3 Economic Impact of Active Disposal Sites

The remedial alternatives and associated costs identified by the 15 field visits permitted CEL to estimate an overall economic assessment for all 39 disposal sites. This was accomplished by categorizing the remaining 24 disposal sites according to geographical location, and thus identify

certain physical and environmental characteristics. Those nonsurveyed sites situated in the same geographic regions as the survyed sites were assumed to have similiar problems in meeting the Federal criteria. Table 2-1 shows the economic results of this analysis. The estimated capital costs for constructing the recommended remedial alternatives is approximately \$4.7 million, with annual operation and maintenance (O&M) of \$330,000.

CRITERIA	Expenditures For Upgrading 39 Disposal Sites	
	Total Capital Costs *	Total O&M Costs *
Floodplains	600K	14K
Endangered Species	-	-
Surface Water	1905K	60K
Groundwater	546K	185K
Disease	-	-
Air	-	-
Safety		
Gas	25K	35K
Fire	-	-
Bird Hazard	-	-
Access	663K	36K
total construction	3739K	
9% engineering	337K	
	4076K	
15% contingency	611K	
	4687K	330K
TOTAL: Capital Costs 4687K O & M Costs 330K		

* Costs are based on 1979 figures.
(-) No expenditures required.
K $1000

Table 2-1 Criteria Compliance Expenditures for Upgrading Active Navy Disposal Sites

3.0 RECOMMENDATIONS AND CONCLUSIONS

3.1 Active Disposal Sites

The RCRA and subsequent 40 CFR 257 criteria requires the disposal of solid waste to be in a manner that minimizes the possibility of adverse effects on health or the environment. From the information provided by the contractor it appears that the 39 active disposal sites owned by the Navy will require minor upgrading (in most cases) to comply with these regulations. The most serious problem facing these landfills will be compliance with the groundwater criteria. It is recommended that monitoring wells and periodic water sampling procedures be established at each disposal site to assess any potential adverse effects.

3.2 Future Disposal Sites

The fact that many Navy installations are located in areas of the U.S. that are typified by wetlands topography presents the Navy with the unique and more difficult problem of disposing of solid waste in an environmentally suitable area. Should the Navy decide to pursue land disposal in a wetlands it must be prepared to face a long, difficult, and expensive permitting process and possible legal action. At this time it is not recommended that wetland environments be considered potential alternatives for disposal of solid waste. Also, the construction of a new landfill in a non-wetland area should be given serious consideration when future disposal alternatives are being evaluated.

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PREFACE

The Civil Engineering Laboratory (CEL), as part of the NAVFAC Solid Waste R&D Program, performed an assessment of alternatives for upgrading Navy solid waste disposal sites. The purpose of this effort was three fold: (1) to determine the extent the Navy may have to modify its current solid waste disposal practices to enable complicance with Section 4004 of the Resource Conservation and Recovery Act; (2) to define technological concepts that represent effective upgrading techniques; and (3) to identify research priorities concerning the technologies for solid waste disposal that are aligned with the Navy's need to maintain its land disposal capability while minimizing cost and manpower requirements. The results of this effort will assist Engineering Field Division (EFD) and Public Works (PW) personnel in characterizing the problems facing their facilities with regards to continued on-base disposal operations, identifying areas of concern in the development of new facilities in wetland and non-wetland areas, and to provide information on the methods and cost of upgrading and/or developing new and existing sites to comply with new regulations.

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This document is comprised of three volumes. Volume 1 contains the "Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR 257)," a "Decision Tree" to determine areas of non-compliance for active disposal sites, and the operational procedures necessary for developing future Navy solid waste disposal sites.

Volume 2 provides technological alternatives for upgrading disposal sites in compliance with the criteria, and identifies the associated costs for implementation of these technologies.

Volume 3 presents the findings and recommendations of the study, and the impact of the Federal regulations on the Navy.

1.0 INTRODUCTION

The purpose of this volume is to present accepted remedial technologies, as well as avante-garde alternatives that may be utilized in bringing Navy solid waste disposal sites into compliance with the Federal criteria promulgated under 40CFR257. The technologies are addressed in two parts. The first section deals with a general description, such as applicability, advantages and constraints of the technology, while the second part identifies cost factors involved in implementing these remedial actions. This volume is intended to provide guidance to landfill designers and operators in selecting the most cost effective remedial technology based on an assessment of site specific conditions developed from the decision tree guide provided in Volume 1.

2.0 TECHNOLOGICAL ALTERNATIVES FOR UPGRADING DISPOSAL SITES IN COMPLIANCE WITH FEDERAL CRITERIA

The following discussion outlines control technologies which are available for upgrading Navy solid waste disposal facilities. The technologies are arranged under the type of control problem addressed. These categories are floodplains (2.1), endangered species (2.2), surface water (2.3), groundwater (2.4), disease (2.5), air quality (2.6), and other safety factors (2.7). Every control technology is analyzed for its relative effectiveness and risk. The major factor in this evaluation is the extent of practical experience with the technology, i.e., whether it has been tested, developed, or newly designed.

2.1 FLOODPLAINS

2.1.1 Control by Berms and Dikes

Perimeter berms or dikes (levees) constructed around the landfill are the primary mechanism for isolating the landfill from inundation and/or erosion during a flood. These berms and dikes must be constructed to a height capable of providing protection from the "base flood." The "base flood," also called the "100-year flood," is one with a 1 percent or greater chance of occurring in any year or a magnitude equaled or exceeded once in 100 years. Elevation of base flood crests can typically be determined from local, state, or Federal flood control agencies.

Landfills can be protected from floods by berms or dikes against which refuse can eventually be placed on the inboard slope. Figure 2-1 illustrates the basic levee design, which is employed in all new landfill areas. Figure 2-2 shows an upgrading of an existing levee previously constructed to less than 100-year flood level. In this design, a compacted soil blanket is placed on refuse slopes to provide additional required protection.

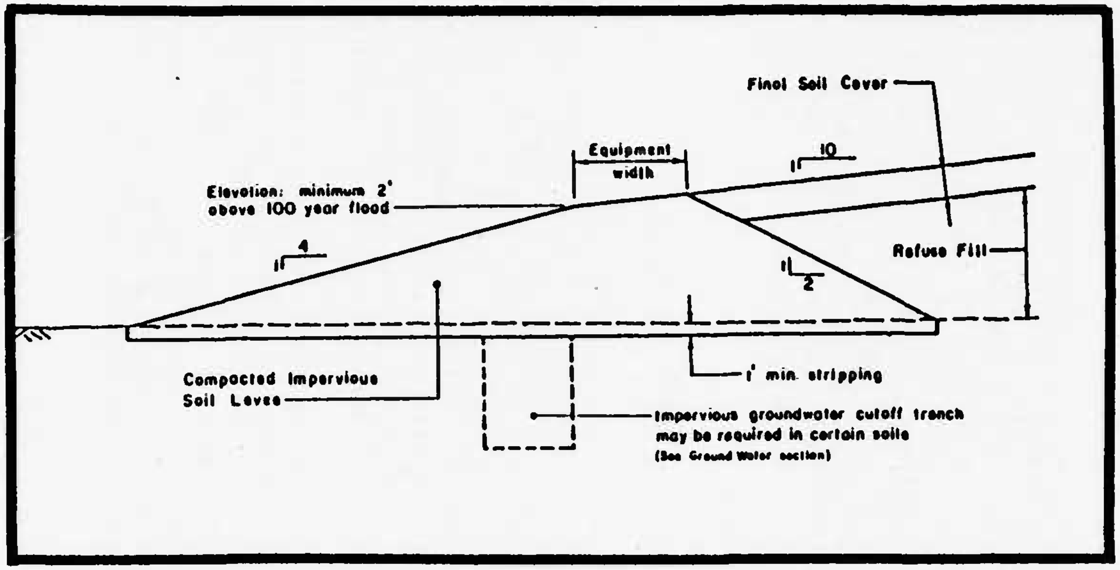


Figure 2-1. Typical Levee

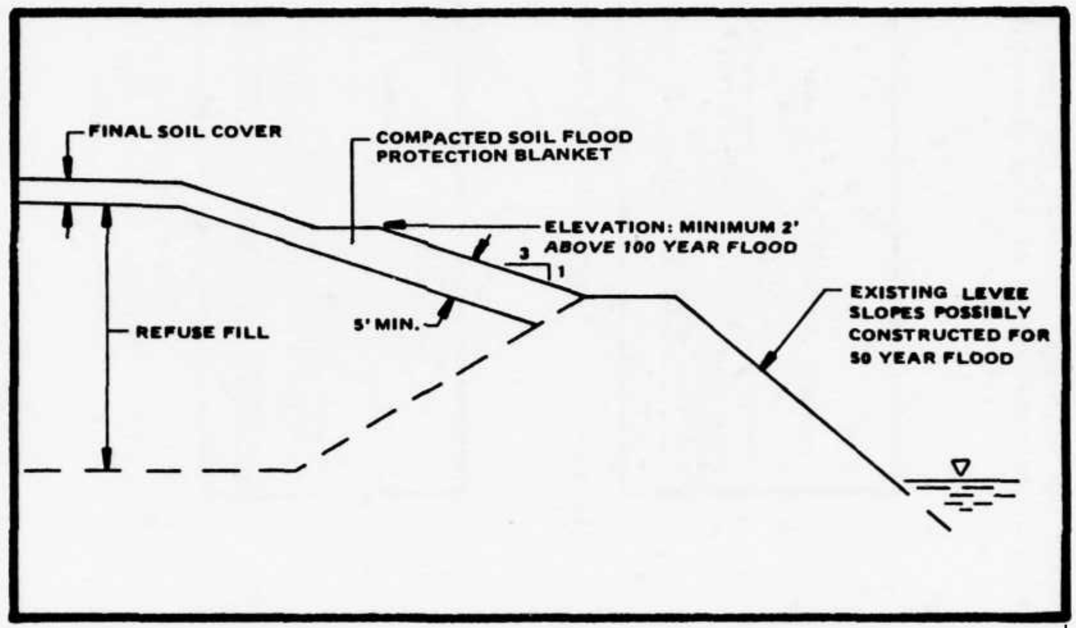


Figure 2-2. Levee Improvement Detail

Levees are constructed ideally of erosion-resistant, low-permeability soils, preferably clay. Most levees are homogeneous embankments; however, if impermeable fill is lacking or if seepage through and below the levee is a problem, then construction of a compacted impervious core or sheet pile cutoff extending below the levee to bedrock (or other impervious stratum) may be necessary. Figure 2-3 depicts these two special cases. Excess seepage through the levees should be collected with gravel-filled trenches or tile drains along the interior of the levee. After draining to sumps, the seepage can be pumped out over the levee. Levee bank slopes, especially those constructed of less desirable soils (silt, sands),

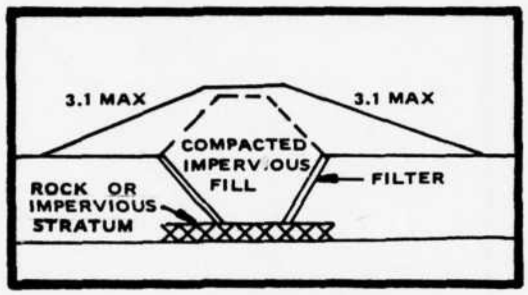


Figure 2-3A Levee with Impervious Core

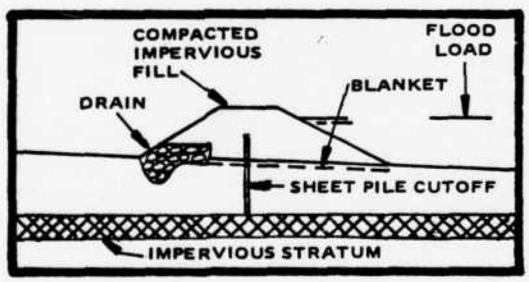


Figure 2-3B Levee with Cutoff and Drain
(Source: Tourbier and Westmacott, 1974)

should be protected against erosion by sodding, planting shrubs and trees, or using stone riprap (Linsley and Franzini, 1979).

Fill material used in levee construction should be compacted in layers, with the least pervious layer along the river side of the levee. Because the use of levees will reduce floodplain storage capacity, fill material should be dredged from borrow pits within the floodplain to provide alternate storage volume for floodwaters. This measure will help control rising flood peaks and prevent an increase in depth of downstream flood stage (Tourbier and Westmacott, 1974).

Storm runoff from precipitation on the drainage areas behind the levee may cause backwater flooding. To handle such interior drainage, upslope interceptor ditches, diversions, or grassed waterways can be used to channel runoff to downslope holding basins (for subsequent pumping) or to off-site streams for natural gravity discharge. Another method to handle backwater flow is the discharge beneath the levee. These conduits should be equipped with tidal gates or backwater valves to prevent backflow and regulate discharge.

Figure 2-4 illustrates a design for protecting existing vulnerable landfill slopes where construction of levees is impractical due to a lack of soil or limited distance to property line. As in Figure 2-2, a protective soil blanket is constructed.

Each of the above designs has been successfully implemented at an existing landfill.

2.1.2 Control by Floodwalls

At sites where refuse capacity must be maximized, the height of constructed lifts may necessitate buttressing to ensure containment of refuse. When such sites are located within floodplains, construction of concrete floodwalls to ensure the isolation of refuse from adjacent floodways could be considered. However, the use of concrete floodwalls at disposal sites must be approached with caution, since some leachates are sufficiently acidic to corrode and thus permeate the concrete. Moreover, such retaining walls must be designed with due concern for the hydrogeologic environment, particularly the degree of stability of site soils and groundwater conditions. Specific disadvantages of floodwalls used to contain refuse are their extremely high cost and their still unproven ability to retain leachate and/or resist corrosion by an acidic leachate.

Illustrated in Figure 2-5 are conceptual designs of four basic floodwall structures: (1) gravity, (2) cantilever, (3) counterfort, and (4) buttressed. The selection of a particular design is based on soil conditions and desired height. Gravity walls are typically used for walls less than 15 feet high; cantilever, 20 to 25 feet; counterfort, greater than 20 feet. Although similar in many respects to counterfort walls, buttressed walls differ in having the backfill on the opposite side of the verticle brackets (buttresses).

The construction of floodwalls to contain refuse is an innovative use of a structural form that has usually been restricted to conventional civil engineering applications. It is important to stress that the design of floodwalls for disposal sites must be tailored to the

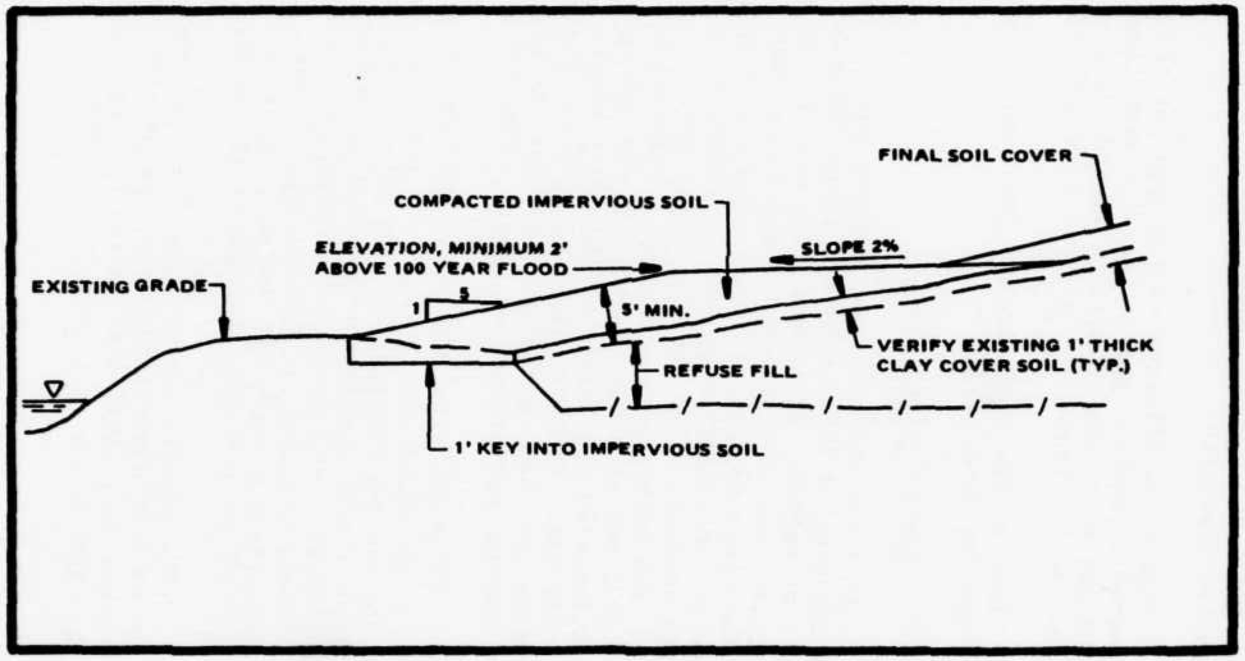


Figure 2-4. Perimeter Flood Protection Detail

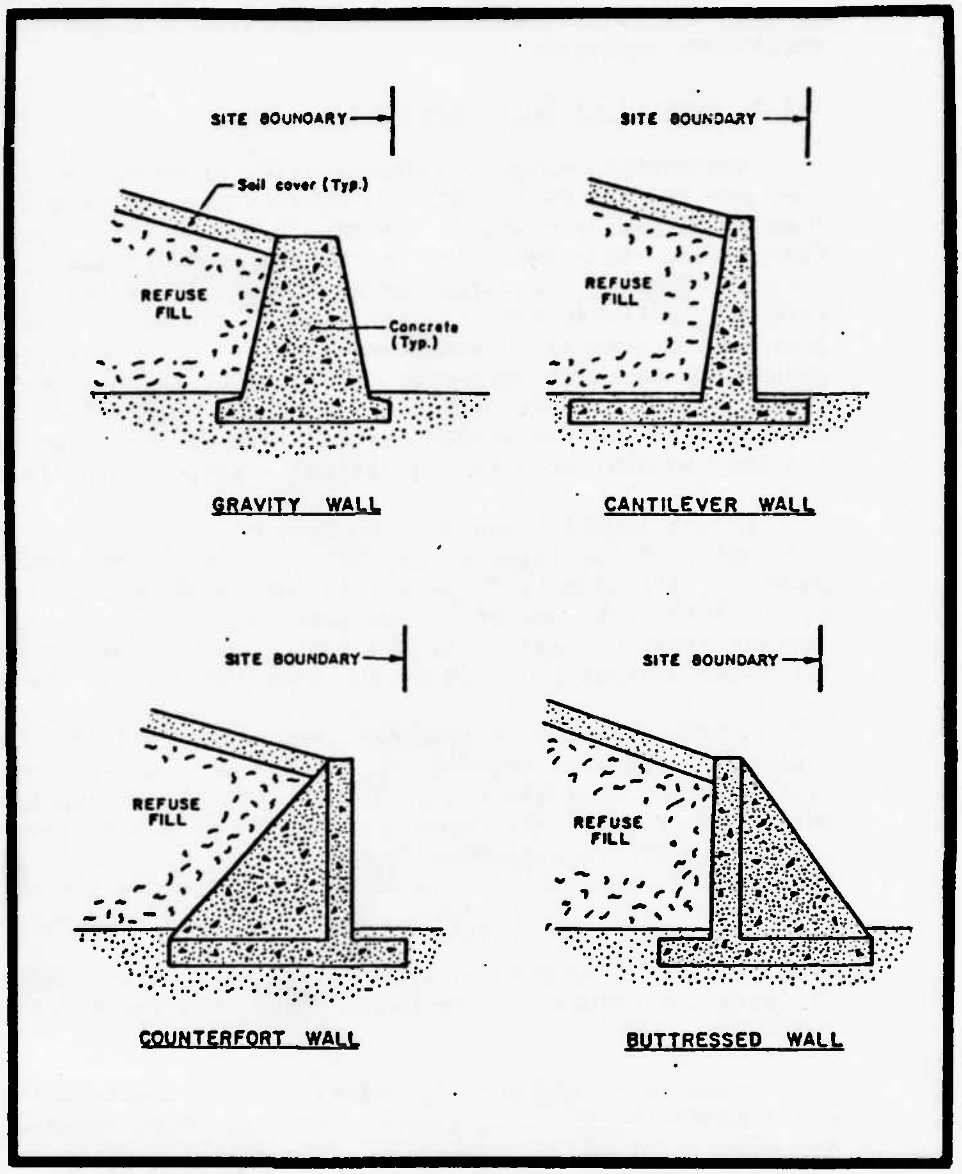


Figure 2-5 Floodwalls

specific geological and groundwater conditions, as well as to the composition of the leachate. Finally, to ensure that floodwall design conforms with regulatory standards, engineers are advised to seek the assistance of the appropriate local and state regulatory agencies.

2.1.3 Control of Backwater Impact

Successful design and construction of perimeter berms, while they may isolate facilities and thereby protect them against inundation and/or erosion, can reduce the storage capacity of the floodplain. This reduction in storage capacity can alter backwater flows, affecting the direction and magnitude of the flow of water through the floodplain and occasionally diverting floodwaters into new, previously unthreatened lands. Adverse effects of perimeter protection can most obviously be precluded or minimized by siting the landfill where it will not impact the water flow, basin storage capacity, or the "backwater curve." The consequences of siting choices can only be evaluated by a qualified engineer or hydrologist.

If the landfill can not be sited to allow normal water flow, the impact of the facility can be minimized by the creation of an equal or offsetting storage volume for floodwaters in the vicinity of the fill. The use of borrow pits, dredged areas, or natural storage areas not naturally accessable to floodwaters may all increase the water storage capacity of the area immediately around the fill.

Borrow pits are excavations from which soil is taken and not replaced. The pits created can enhance the water storage capacity of the area around the fill. If soils for levee construction and use as daily cover are taken from borrow pits near the fill and within the 100-year floodplain, the volume of floodwater storage displaced by the fill can be partially offset by the volume of the pits. Similarly, if dredge spoils taken from adjacent wetlands or the river or estuary itself are used to build dikes, the dredged areas will provide greater water storage capacity. Additionally, dredging and channeling the water source can reduce the volume of overflow.

Other low-lying areas or wetlands near the landfill but not within the floodplain may be used to enhance its water storage capacity. For example, a wetland separated from the floodplain by a low rise or similar natural embankment can be connected to it through conduits or ditches, thus increasing floodwater capacity.

Other alternatives in minimizing backwater impacts include construction of additional drainage ways, channel improvements (including dredging, lining, etc.), and deflector systems to minimize velocity reduction along banks and berms strategically located in the floodplain.

Each of these alternatives must be evaluated on a site-by-site basis and discussed with appropriate regulatory agencies before a plan is selected and implemented.

2.2 ENDANGERED SPECIES

Each form of wildlife has its own requirements for water, cover, food, space, quiet, and other basic needs. The wide range of species listed under Section 4 of the Endangered Species Act makes it impossible to present a comprehensive list of technological alternatives for ensuring their survival. Each site, existing or proposed, should be surveyed by a wildlife biologist to establish the kinds of wildlife inhabiting the property, which of these are considered "endangered" or "threatened," and the special characteristics and needs of these endangered species. Only then can precise technologies be developed for protecting them.

2.2.1 Protecting Endangered Species

In general, whenever endangered species are present at a site, alternative locations for the landfill should be considered. However, disposal sites compatible with the established ecosystem can be constructed. Special care may be needed to ensure that appropriate water, air and noise quality levels are maintained and that the particular species' topographic, soil, vegetation, and space requirements are met during and after construction. Only through careful understanding of the species in question can the proper technologies for their protection be selected and economically evaluated.

2.2.2 Protection Through "Selective Landfilling"

One innovative approach to protecting endangered species is "selective landfilling," where portions of land within or near a proposed landfill are preserved and enhanced for wildlife support to compensate for land lost to filling. The result of such a creative design approach to landfilling can be a varied topographic and aquatic environment capable of supporting a wide range of wildlife. Design elements of such a plan may include carefully planned dredging, filling, channeling, ponding, or landscaping selected to create an ecologically diverse environment for many creatures. Figure 2-6 illustrates this concept.

Such a design is currently being developed in Salt Lake City, Utah, where a wildlife refuge is being planned in conjunction with expansion of a landfill. The city has an existing landfill and plans to expand onto adjacent lands bordered by property owned by the Utah Division of Wildlife Resources. The plan is a joint effort to develop increased

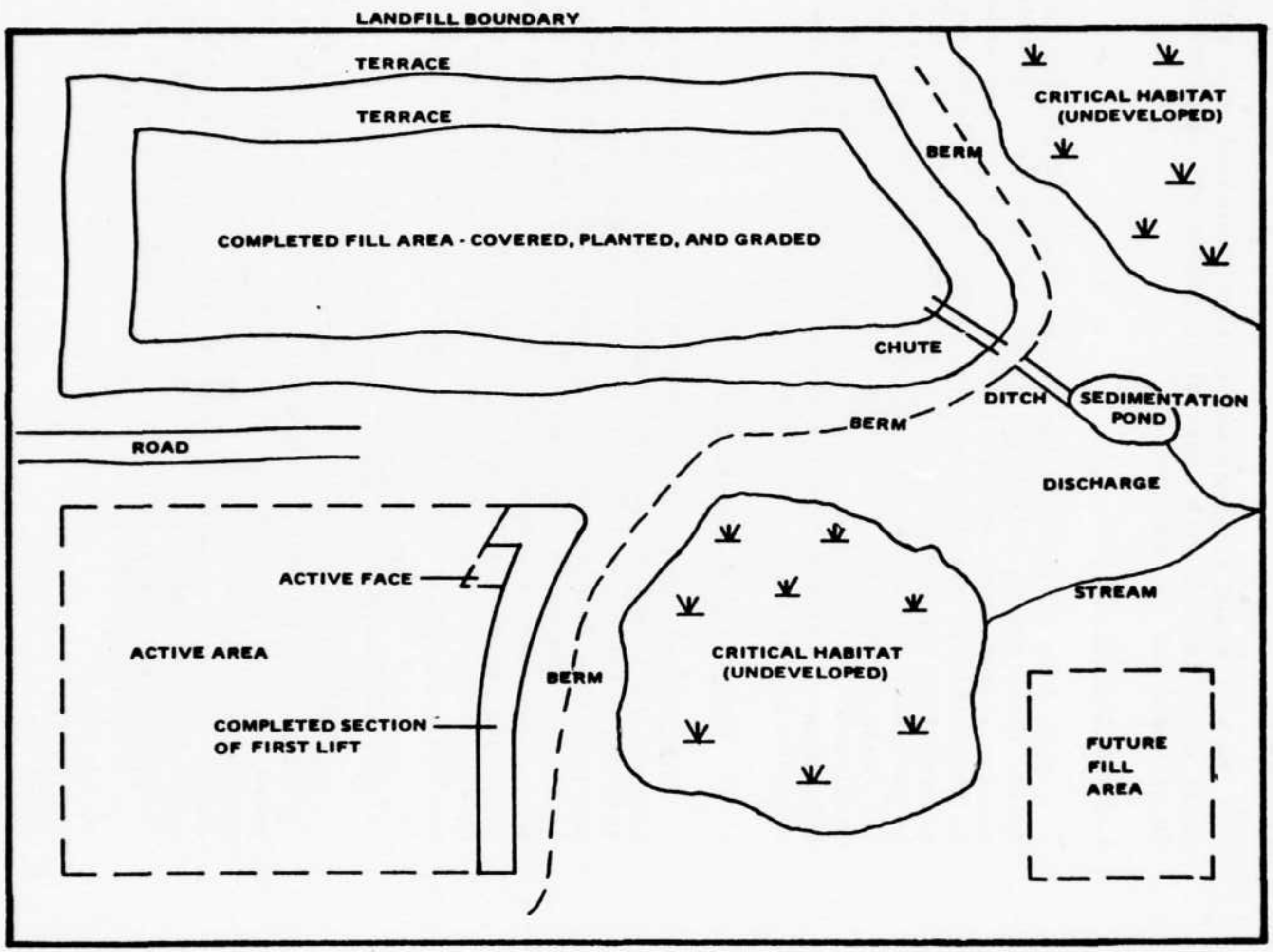


Figure 2-6. Selective Landfilling

refuse capacity while maintaining an environment that protects flora and fauna.

In the proposed project, portions of the refuse will be used to create elevations that act as screening and buffer zones separating different recreational and habitat areas on the wildlife parcel. In addition, excavations from which cover material is taken will subsequently be filled with water to provide open water and marsh areas. Such areas will serve as buffers between landfilling and will provide support for a wider range of animal life. The resulting plan will protect wildlife from human intrusion while providing an enhanced habitat.

Before a creative design such as this is developed for a given location, an ecologist should survey the proposed site to identify areas that are most and least productive and feeding areas for the endangered or threatened species, and advise what changes would enhance the ecologic productivity of the site. In addition, if selective landfilling is planned, requirements for state and local regulatory permits must be met.

2.2.3 Designating "Mitigation Land"

Another approach to alleviating the impact of landfilling is the use of "mitigation land." The concept of mitigation land involves compensating for the loss of ecological value of land lost (to landfilling) by providing a parcel of land roughly equal in size and equivalent in productive value to that lost. An innovative concept in the field of solid waste disposal, mitigation land has been set aside in a few landfilling projects involving wetlands. With respect to endangered or threatened species, land lost through landfilling would be compensated through an enhanced habitat that would mitigate the threat to the species affected. The use of mitigation land is a political solution, rather than a technology.

Use of mitigation land relies on the availability of adjacent or nearby lands to which populations of the species in question can migrate. The landfill can be constructed in stages, leaving most of the ultimate landfill area free from development shifts. This concept has been applied at a site north of San Francisco where a parcel of land south of an area proposed for waste disposal has been designated as mitigation land. This arrangement will compensate for an existing disposal operation (owned by the same company) that is considered to be seasonal wetlands. If the plans are approved by the appropriate state and local agencies, mitigation land -- equal in area to that proposed for the santitary landfill -- will be deeded to the California Department of Fish and Game.

At another California site, mitigation lands were incorporated in the plans proposed for a sanitary landfill located on the site that was once part of the marshlands of San Francisco Bay. The end use plan calls for converting abandonded salt ponds to ten acres of tidal (saltwater) marshland and nine acres of freshwater lake or marsh. The tidal water will allow natural siltation of the area and ultimately produce a mixed habitat for plants and animals. The proposed freshwater lake is expected to attract a variety of birds and mammals, thereby enhancing the value of the proposed bay-front park.

The practicality and cost effectiveness of setting aside mitigation land must be assessed on a case-by-case basis.

2.2.4 Deep or Vertical Landfilling

In some cases, it is possible to minimize the effect of a landfill on a critical habitat by minimizing its surface area and by increasing its vertical extent, thus maintaining the same volume. This may be accomplished through excavation of deep trenches and/or continuation of the landfill as an area or rampfill above the ground surface. The possible height of the landfill depends upon several factors:

- Depth to groundwater
- Bearing strength of soil
- Degree of compaction
- Availability of cover material
- Grading and/or runoff control measures.

The fill should not be dug deeper than 1.5 meters above the mean seasonal high water table. The soil and rock underlying the site should be of sufficient bearing strength not to subside under the additional loading caused by successive lifts. Additionally, waste compaction must be thorough to prevent subsidence in the lower lifts as additional lifts are applied. Finally, as lifts are progressively built above ground level, their areal extent will become smaller due to grading and terracing of the side slopes. Proper terracing, grading, ditching, and benching of the landfill slopes is a necessity in this type of landfill, since slope erosion will expose waste materials and allow wastes to wash out and be excessively infiltrated by precipitation. Planting or riprap is necessary on side slopes to prevent erosion.

2.3 SURFACE WATER

Surface water quality may be directly affected in two ways by the presence of an active landfill operation. First, runoff from bare landfill surfaces, carrying sediment and/or solid wastes, adds to turbidity and nutrient levels of surface water. Second, contaminated leachate reaches the body of water -- either directly, as seepage runoff or seepage from a contaminated aquifer into a stream below surface water level, or indirectly, carried by surface runoff. Many of the technologies discussed in this section will address both these problems. For instance, proper ditching removes water from the landfill surface quickly, reducing infiltration and leachate production and, concomitantly, leachate seepage. At the same time, it allows collection and settling of runoff prior to discharge into the affected body of water, reducing its effects on turbity.

The technologies which significantly affect both negative impacts of landfills on surface water quality include the following:

- Ditches, diversions, waterways
- Terraces and benches
- Chutes and downdrains
- Drainage systems
- Surface grading
- Surface capping

Additionally, the following technologies affect one of the negative impacts:

- Sedimentation pond (surface runoff)
- Liners (leachate)
- Leachate seepage collection (leachate)

2.3.1 Ditches, Diversions, Waterways

Sites located in hill and lowland areas are of special concern in regard to the control of surface runoff. Drainage facilities (diversions, waterways, and drainage ditches) must be located to isolate the landfill from surface runoff by diverting all off-site and contributory drainage around the landfill. Diversion drainage is of special concern in canyon landfills, where the fill is essentially "blocking" existing drainage and the landfills are susceptible to large amounts of surface infiltration from off-site sources.

Ditches (or swales) are temporary drainage ways excavated above and below disturbed areas to intercept and divert runoff. They may be constructed along the upslope perimeter of disposal areas to intercept storm runoff and carry it to natural drainage channels downslope of the site. As shown in Figure 2-7, ditches may also be installed downslope of covered disposal sites to collect and transport sediment-laden flow to sediment traps or basins. Ditches should be left in place until the disposal site is sealed and stabilized with cover vegetation.

Diversions are permanent or temporary shallow drainage ways excavated along the contour of graded slopes with a supporting earthen ridge (dike or berm) constructed along the downhill edge of the drainage way. Essentially, a diversion is a combination of a ditch and a dike (U.S. EPA, 1976). Diversions are used primarily to provide more permanent erosion control on long slopes subject to heavy flow concentrations. They may be constructed across long slopes to divide the slope into nonerosive segments. Diversions may also be constructed at the top or at the base of long graded slopes at disposal sites to intercept and carry flow at nonerosive velocities to natural or prepared outlets (e.g., level runoff spreaders). Diversions are recommended for use only on slopes of 15 percent or less (U.S. EPA, 1976).

Grassed waterways (or channels) are graded drainage ways that serve as outlets for diversions or berms. Waterways are stabilized with suitable vegetation and are generally designed to be wide and shallow in order to convey runoff down slopes at nonerosive velocities. Waterways may be constructed along the perimeter of disposal sites located within natural slopes, or they may be constructed as part of the final grading design for disposal areas that have been capped and revegetated.

Ditches, diversions and waterways are generally V-shaped, trapezodial or parabolic in cross-section. The specific design will will depend on local drainage patterns, soil permeability, annual precipitation, area land use, and other pertinent characteristics of the contributing watershed. In general, such drainage ways should be designed to accommodate flows resulting from rainstorms of 10- to 25-year frequency. More importantly, they should be designed and constructed to intercept and convey such flows at nonerosive velocities.

Figure 2-8 depicts the effect of drainage ditch shape on relative velocity (and erosivity) of conveyed flows. In general, the wider and shallower the channel cross-section, the less the velocity of contained flow and, therefore, the less the potential

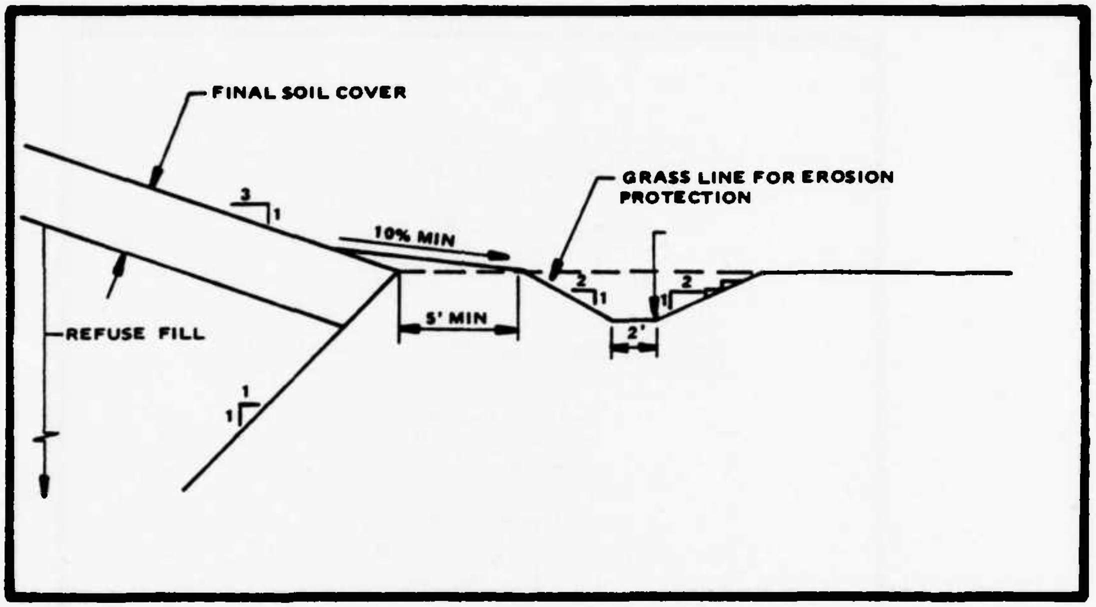
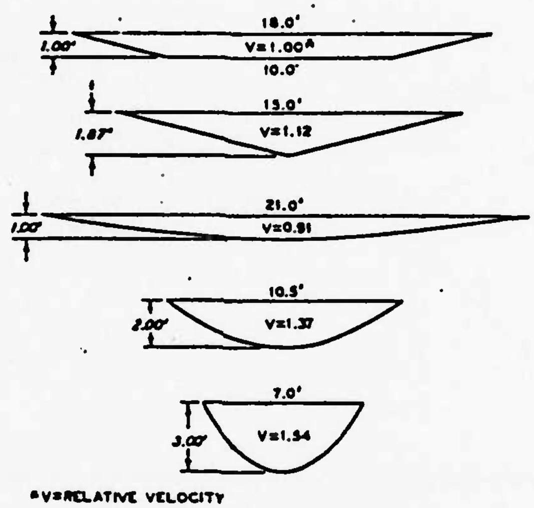


Figure 2-7. Typical Diversion Ditch at Base of Disposal Site

for erosion of drainageway side slopes. Where local conditions necessitate building narrower and deeper channels, or where slopes are steep and flow velocities are excessive, the channel will require stabilization through seeding and mulching or the use of stone riprap to line channel bottoms and break up flow.



Effect of Drainage Ditch Shape on Velocity and Erosivity

(Source: Lutton, et al., 1979)

Figure 2-8

Table 2-1, below, presents maximum permissible design velocities for flow in diversion ditches and ground waterways, based on the channel grade and stabilizing cover material.

Table 2-1 Permissible Design Velocities for Stabilized Diversions and Waterways

(Source: U.S. EPA, 1976)

COVER	CHANNEL GRADE (%)	MAXIMUM DESIGN VELOCITY (FT/SEC)
Vegetative		
• Bermuda grass	0-5	6
	5-10	5
	10	4
• Reed canary grass; Tall fescue; Kentucky bluegrass	0-5	5
	5-10	4
	10	3
• Grass-legume mix	0-5	2.5
	5-10	3
• Red fescue; Redtop, Sericea lespedeza	0-5	2.5
• Annuals; Small grain (rye, oats, barley); Ryegrass	0-5	2.5
Mechanical and Vegetative		
Stone Center	All	As determined from vegetative cover above

Figure 2-9 shows the standard design for diversion ditches. These structures are designed for short-term application only, for upslope drainage areas of less than 5 acres. A minimum grade of 1 percent, draining to a stabilized outlet such as a grassed waterway or, where necessary, to a sediment basin or trap, is recommended for temporary diversion ditches. For channel slopes greater than 5 percent, stabilization with grasses, mulches, sod, or stone riprap will be necessary. As with all temporary diversion structures, periodic inspection and maintenance are required to ensure structural integrity and effective performance (U.S. EPA, 1976).

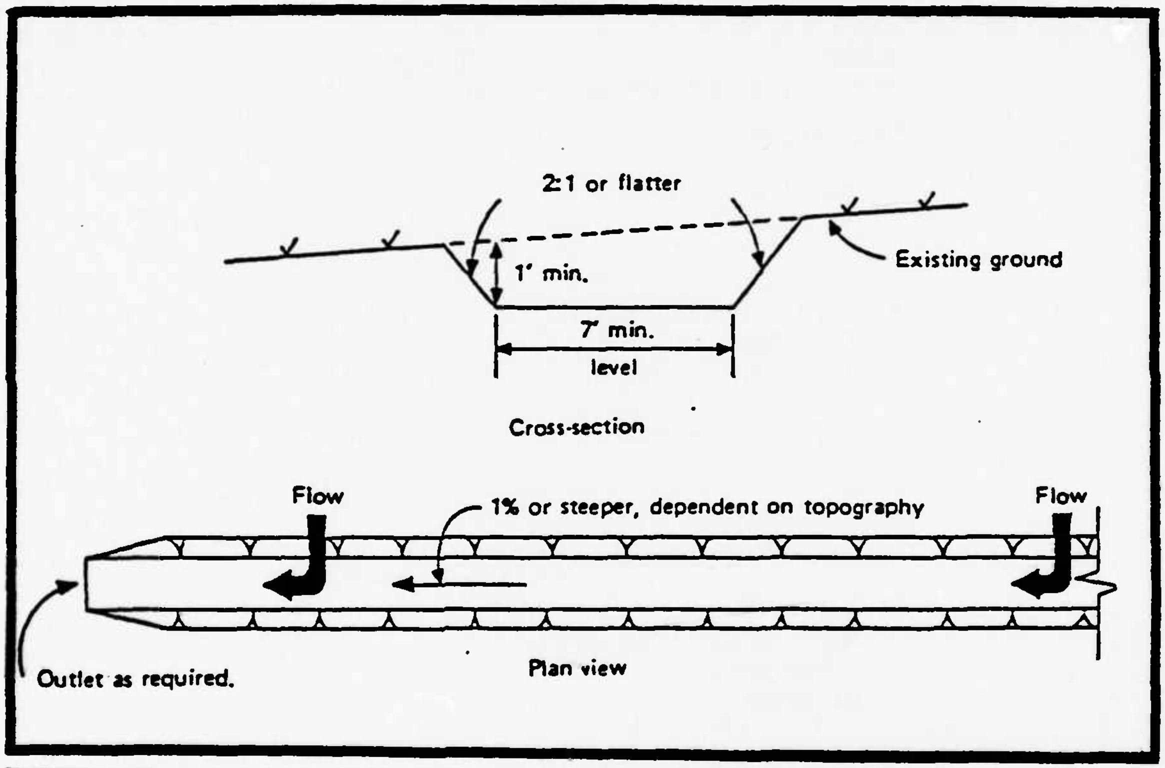


Figure 2-9 . Temporary Diversion Ditch/Swale
(Source: U.S. EPA, 1976)

Figure 2-10 presents general design features of parabolic and trapezoidal diversions. A formal design is not required for diversions used as temporary water-handling structures. General design and construction criteria for permanent diversions include the following (U.S. EPA, 1976):

- Diversion location is determined based on outlet conditions, topography, soil type, slope length and grade.
- The constructed diversion should have enough capacity to carry the peak discharge from a 25-year design storm.
- The maximum grade of the diversion can be determined from design flow velocities obtained after stabilization by various vegetative covers (Table 4-1 above).
- The diversion channel should be parabolic or trapezodial in shape, with side slopes no steeper than 2:1.
- The supporting ridge (dike or berm) should be at least 4 feet wide; the free board (distance from peak water level to top of channel) should be at least 0.3 feet.
- Each diversion shall have a stable outlet such as a natural waterway, stabilized open channel chute, or downpipe.
- Stabilization: for design velocities <3.5 ft/sec, the channel should be stabilized with seeding and mulching for vegetative establishment; for velocities >3.5 ft/sec, sod or seeding protected by jute or excelsior matting should be used.
- For channels with base flow, install a stone center (riprap stabilization) for grassed waterways; subsurface drainage with gravel/stone trenches may be required where the water table is at or near the surface of the channel bottom.
- Fills shall be compacted as needed to prevent unequal settlement.
- All trees, bushes, stumps, and obstructions should be cleared to prevent improper functioning of the channel.

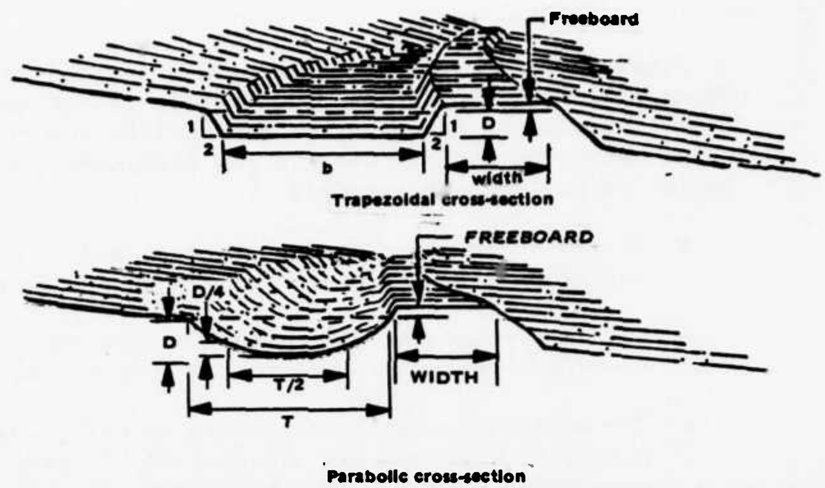
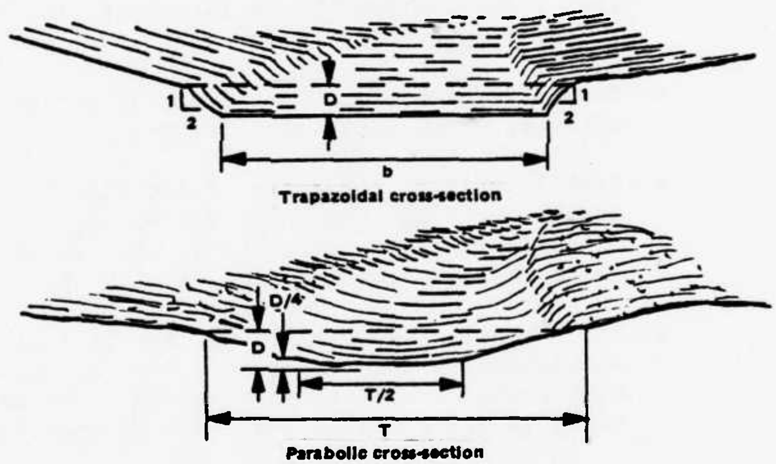


Figure 2-10

Diversions
(Source: U.S. EPA, 1976)



Grassed Waterways
(Source: U.S. EPA, 1976)

Figure 2-11

Figures 2-11 and 2-12 depict general design configuration for grassed waterways. The design and construction criteria presented above for diversions are applicable to grassed waterways also.

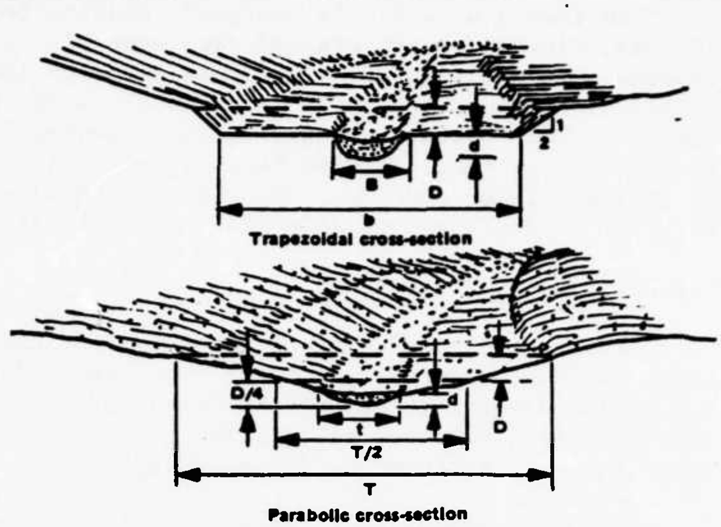
When they are carefully designed, constructed and maintained, ditches, diversions and grassed waterways will control surface erosion and infiltration at disposal sites by intercepting and safely diverting storm runoff to downslope or off-site outlets. When situated at the base of disposal site slopes, they function to protect off-site habitat from possible contamination by sediment-laden runoff. These structures are generally constructed of readily available fill by well-established techniques.

2.3.2 Terraces and Benches

Terraces and benches are relatively flat areas constructed along the contour of very long or very steep slopes to slow down runoff and divert it into ditches or diversions for off-site transport at nonerosive velocities. These structures are also known as bench terraces or drainage benches.

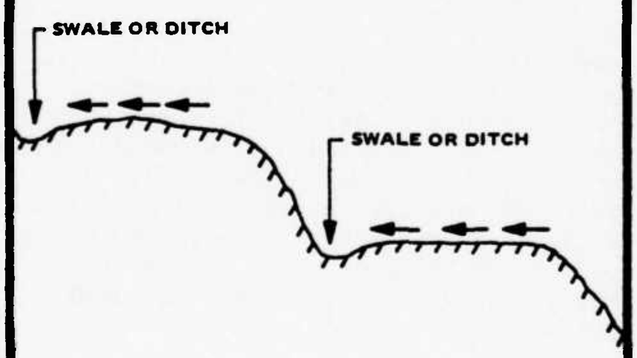
Although benches and terraces are slope reduction devices, they are generally constructed with reverse fall or natural fall (see Figure 2-13) to divert water to stabilized drainage ways. Benches and terraces may be used to break up steeply graded slopes of covered disposal sites into less erodible segments. Upslope of the disposal site they act to slow and divert storm runoff around the site. Downslope of landfill areas, they act to intercept and divert sediment-laden runoff to traps or basins. Hence, they may function to hydrologically isolate active disposal sites, to control erosion of cover materials on completed fills, or to collect contaminated sediments eroded from disposal areas. For disposal sites undergoing final grading (after capping and before revegetation), construction of benches or terraces may be included as part of the integrated site closure plan.

Benches and terraces generally do not require a formal design plan. Figure 2-14 presents the design for a typical drainage bench located on the slope of a covered landfill. This particular bench is designed with a natural fall. Since it is intended for long-term erosion protection, the associated V-shaped channel is asphalt concrete-lined. Diversions and ditches included in bench/terrace construction may be seeded and mulched, sodded, stabilized with riprap or soil additives, or stabilized by any combination of these methods. Lining the channels with concrete or grouted riprap is a more costly alternative.



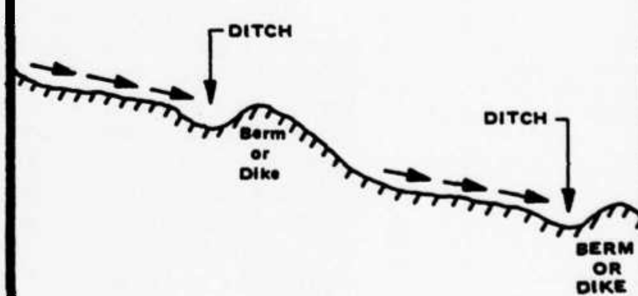
Grassed Waterways with Stone Centers
(Source: U.S. EPA,1976)

Figure 2-12



BENCH TERRACES WITH REVERSE FALL

Figure 2-13A



BENCH TERRACES WITH NATURAL FALL
(ADAPTED FROM TOURBIER AND WESTMACOTT, 1974)

Figure 2-13B

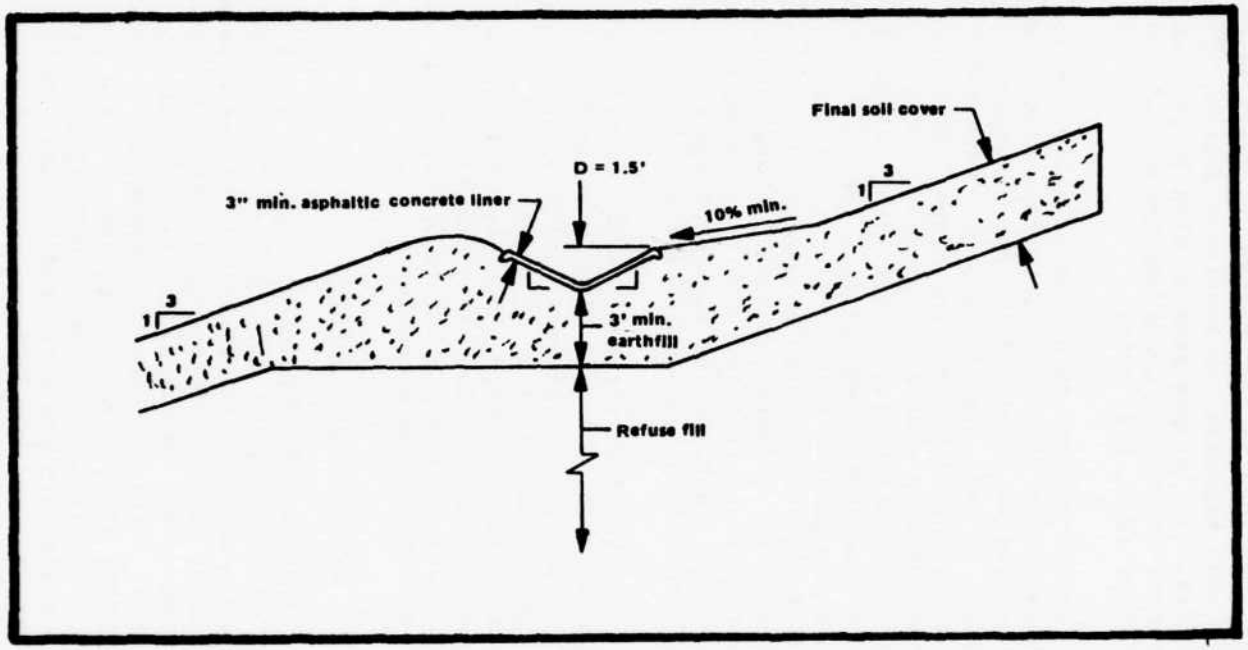


Figure 2-14. Typical Drainage Ditch

The width and spacing between benches and terraces will depend on slope steepness, soil type, and slope length. In general, the longer and steeper the slope and the more erodible the cover soil, the less the recommended distance between drainage benches. This will maximize the erosion reduction afforded by constructed benches. For slopes greater than 10 percent, the maximum distance between drainage benches shoulde be approximately 100 feet (U.S. EPA, 1976).

Bench terraces do not necessarily have to be designed with diversions or ditches to intercept flow. Reverse benches and slope benches (Figure 2-15) may be constructed during final site grading on well stabilized (e.g., vegetated) slopes to enhance erosion control by reducing slope length and steepness. At sites where an effective cap (e.g., clay or synthetic liner) has been constructed, or for sites located in arid regions, these nondrainage benches will function to slow sheet runoff and allow greater infiltration rates which will aid in the establishment of a suitable vegetative cover. For most disposal sites in wet climates, however, where leachate generation and cover erosion are major problems, benches or terraces should be designed in association with drainage channels which intercept and transport heavy, concentrated surface flows safely off-site.

As with other earthen erosion control structures, benches and terraces should be sufficiently compacted and stabilized with appropriate cover (grasses, mulches, sod) to accommodate local topography and climate. They should be inspected during or after major storms to ensure proper functioning and structural integrity. If bench slopes become badly eroded or if their surfaces become susceptible to pooling due to differential settlement, regrading and sodding may be necessary.

2.3.3 Chutes and Downdrains

Chutes and downdrains are used to carry concentrated runoff flows from one level to another. Chutes (or flumes) are open channels, normally lined with bituminous concrete, portland cement concrete, grouted riprap, or similar nonerodible material. These structures may be useful in handling runoff on long, steep slopes at disposal sites. Downpipes (downdrains; pipe slope drains) are temporary structures constructed of rigid piping (such as corrugated metal) or flexible tubing of heavy-duty fabric. They are installed with a standard prefabricated entrance section and are designed to handle flow from drainage areas of 5 acres or less. Like paved chutes, downpipes discharge to stabilized outlets or sediment traps. Downpipes may be used to collect and transport runoff from long, isolated outslopes or from small disposal areas located along steep slopes.

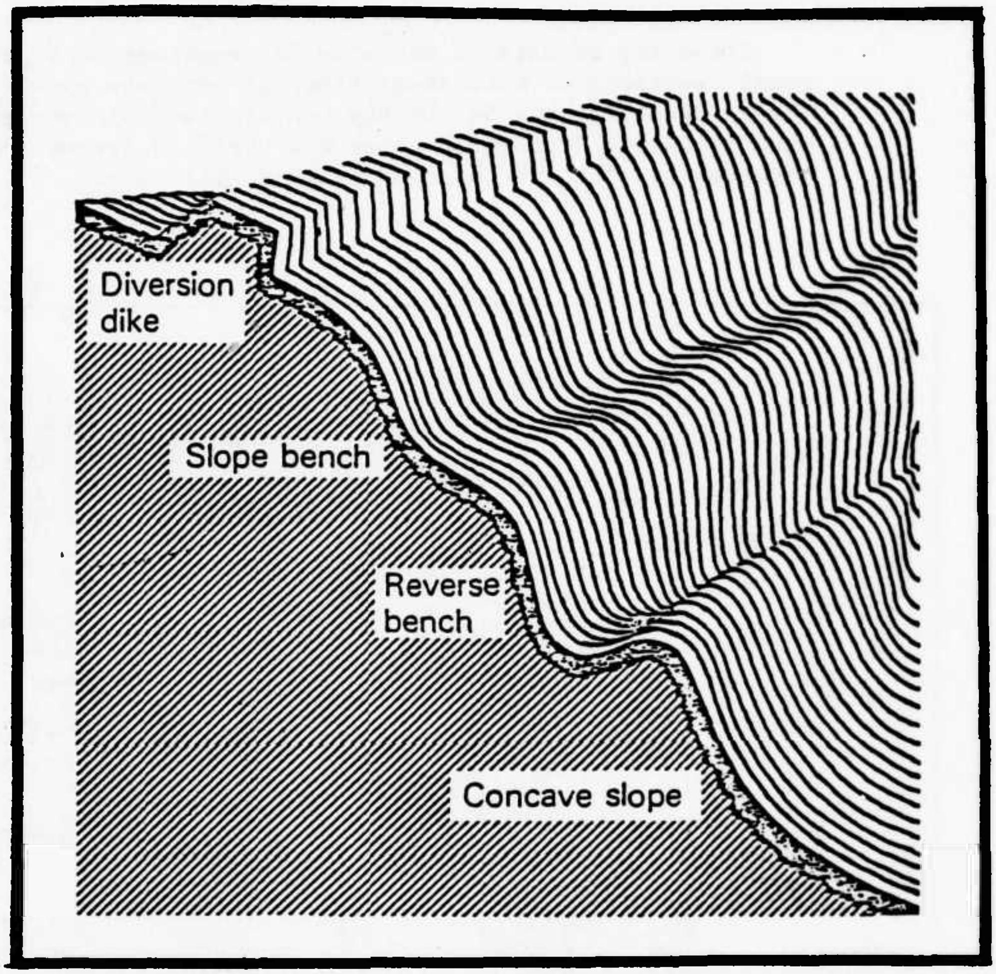
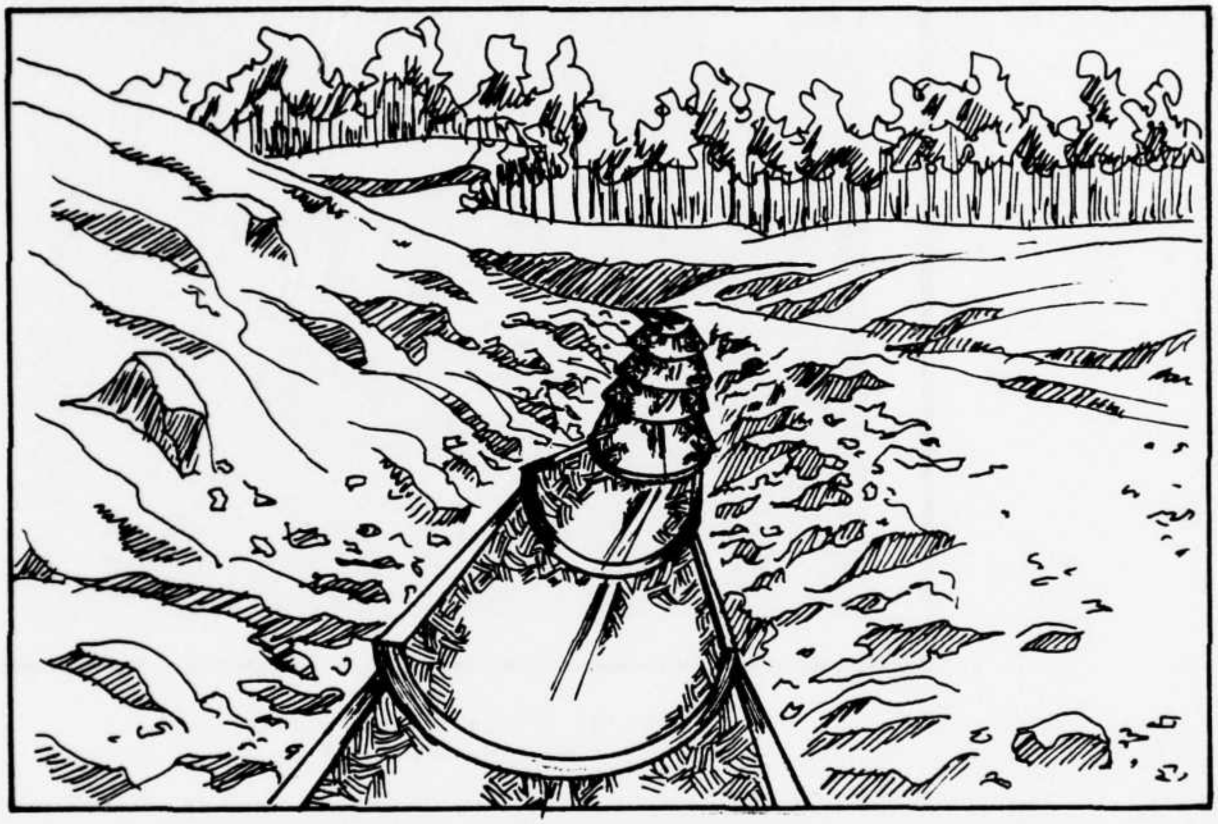


Figure 2-15 Slope Reduction Measures
(Source: U.S. EPA, 1976)

Temporary downdrains may also be constructed by joining half-round sections of bituminous fiber or concrete pipe (Figure 2-16). These structures may be quickly constructed for emergency situations when downslope ditches or waterways overflow during severe storms and threaten to erode the base of disposal fill areas.



Half-round Bituminous Fiber Pipe Used for Temporary Handling of Concentrated Flow

Figure 2-16

Chutes and downpipes are temporary structures which do not require formal design. General design criteria are presented in Figures 2-17 (paved chute), 2-18 (rigid downpipe), and 2-19 (flexible downdrain).

Chutes designs are divided into two basic size-groups. Paved chutes of size group A have the following three qualifications:

- Height (H) of dike entrance = 1.5 feet minimum
- Depth (D) of chute down the slope = 8 inches minimum
- Length (L) of inlet/outlet sections = 5 feet minimum

Similarly, chutes of size group B meet the following criteria:

- H = 2 feet minimum
- D = 10 inches minimum
- L = 6 feet minimum

Table 2-2 below presents the bottom width and maximum drainage area for designed chutes of the two size groups.

Table 2-2. Bottom Widths and Maximum Drainage Areas for Temporary Chutes

Size Group	Bottom Width, D (ft.)[1]	Maximum Drainage Area (acres)	Size Group	Bottom Width, D (ft.)[1]	Maximum Drainage Area (acres)
A-2	2	5	B-4	4	14
A-4	4	8	B-6	6	20
A-6	6	11	B-8	8	25
A-8	8	14	B-10	10	31
A-10	10	18	B-12	12	36

[1] Source : U.S EPA, 1976

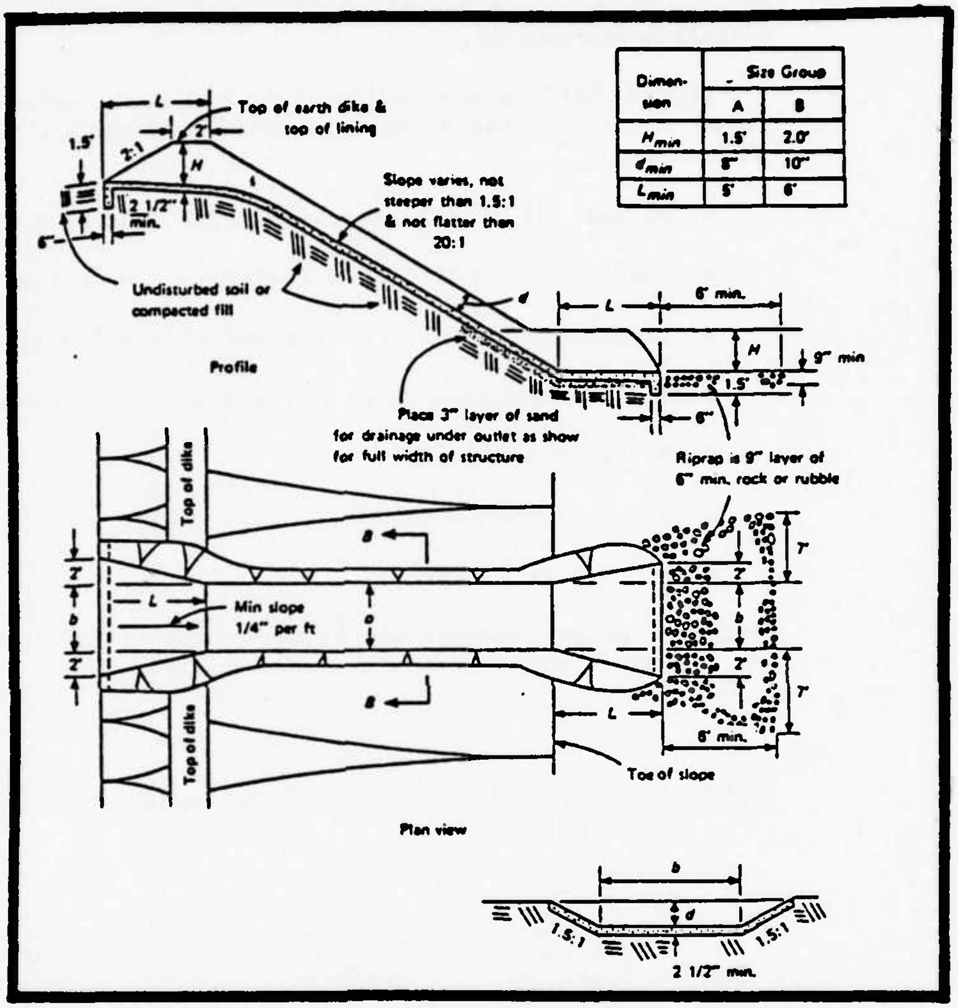


Figure 2-17 Paved Chute (or Flume)
(Source: U.S. EPA, 1976)

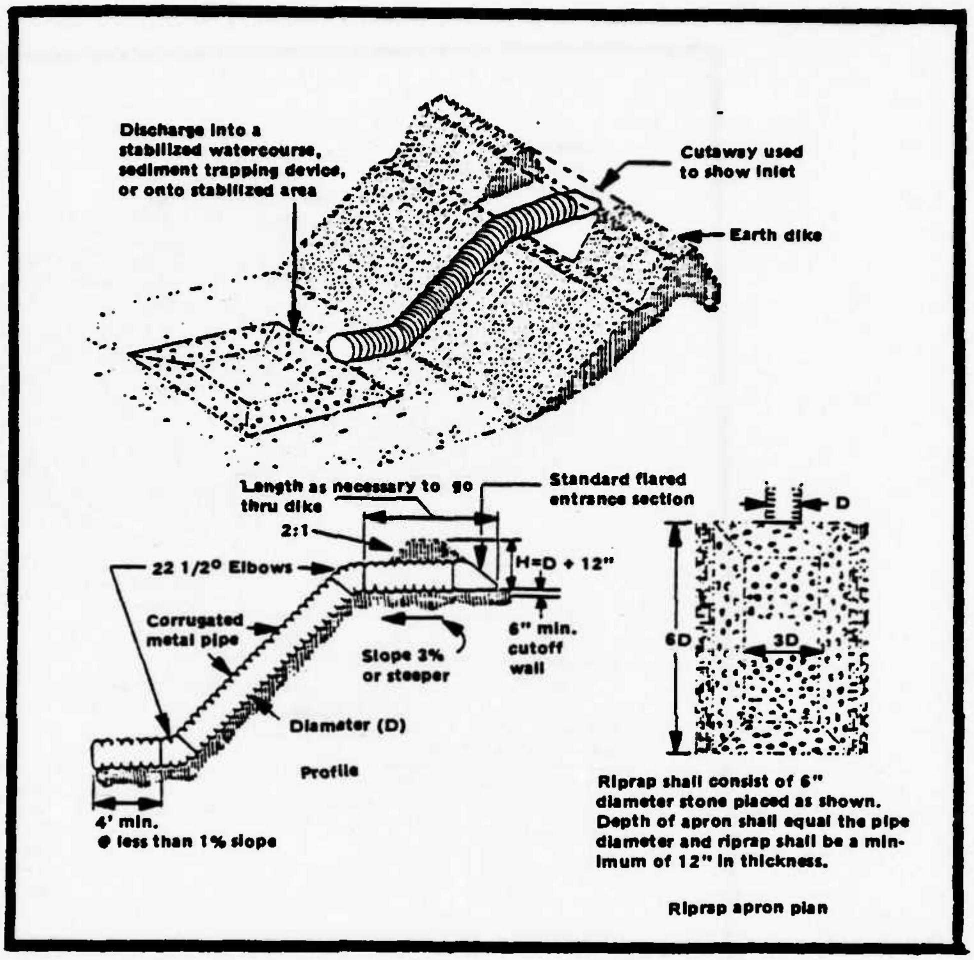


Figure 2-18 Rigid Downpipe
(Source: U.S. EPA, 1976)

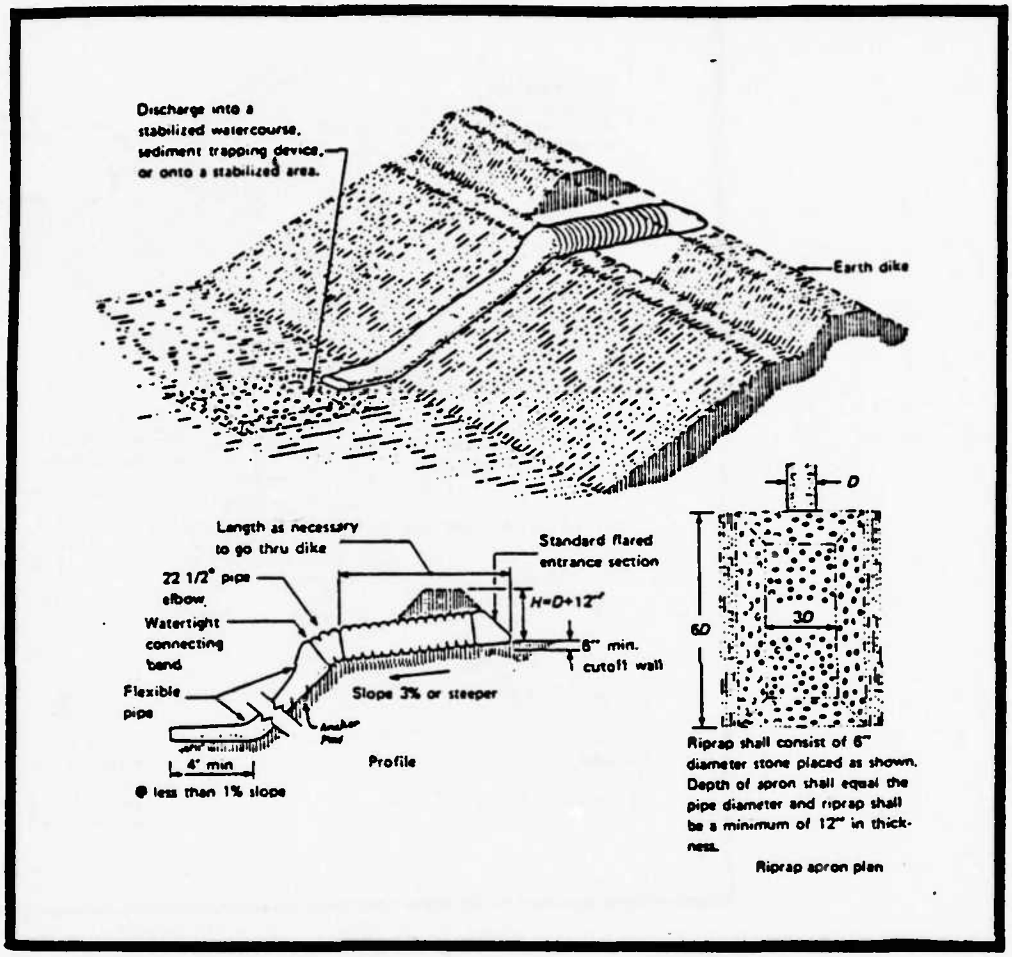


Figure 2-19 Flexible Downdrain
(Source: U.S. EPA, 1976)

If 75 percent or more of the drainage area has good vegetative cover (established grasses and/or shrubs) throughout the design life of the chute, the drainage areas listed in Table 2-2 may be increased by 50 percent. If 75 percent or more of the drained area has a mulch cover throughout the structure's life, the areas may be increased by 25 percent (U.S. EPA, 1976).

Construction considerations for paved chutes include the following (U.S. EPA, 1976):

- The structure shall be placed on undisturbed soil or well-compacted fill.
- The lining shall be placed by beginning at the lower end and proceeding upslope; the lining shall be well-compacted, free of voids, and reasonably smooth.
- The cut-off walls at the entrance and at the end of the asphalted discharge aprons shall be continuous with the lining.
- An energy dissipator (riprap bed) shall be used to prevent erosion at the outlet.

For downpipes (Figure 2-18 and 2-19), the maximum drainage area is determined from the diameter of the piping as follows (U.S. EPA, 1976):

PIPE/TUBING DIAMETER, D (INCHES)	MAXIMUM DRAINAGE AREA (ACRES)
12	0.5
18	1.5
21	2.5
24	3.5
30	5.0

General construction criteria for both rigid and flexible downdrains include the following:

- The inlet pipe shall have a slope of 3 percent or greater.
- For the rigid downpipe, corrugated metal pipe with watertight connecting bands shall be used.
- For the flexible downdrain, the inlet pipe shall be corrugated metal; the flexible tubing shall be in the same diameter as the inlet pipe, securely fastened to the inlet with metal strapping or watertight connecting collars.
- A riprap apron shall be provided at the outlet; this shall consist of 6-inch diameter stone placed as shown in the figures.
- The soil around and under the inlet pipe and entrance sections shall be hand-tamped in 4-inch lifts to the top of the earth dike.

- Follow-up inspection and any needed maintenance shall be performed after each storm.

2.3.4 Drainage System

Gravity drainage systems are designed to remove a specific volume of water from a disposal site in a reasonable amount of time. Complete drainage systems, discussed in this section, consist of filter, a collector or series of collectors, and a basin, sump, or the like for disposal of the collected water.

A drainage system may be used to attain several different objectives. Most frequently it will be used to intercept runoff and infiltration from a site and dispose of or treat the water downgradient of the site. A drainage system may also be used to intercept water around the site for slightly lowering groundwater elevation.

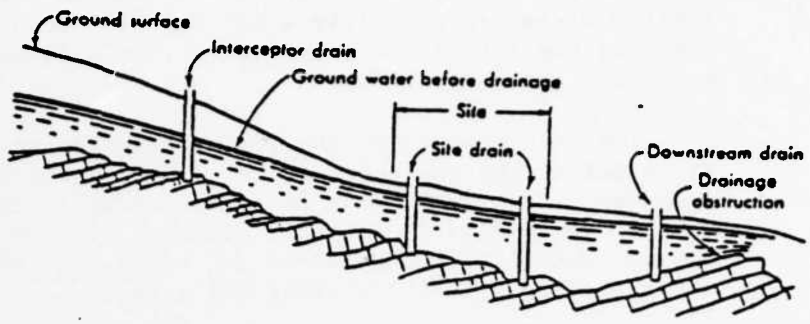
Frequently, the collectors or recharge basin will be used in connection with other remedial action techniques. Collectors may discharge to a treatment system if the water drained from the site is contaminated. Recharge basins may be used in conjunction with a groundwater pumping and treatment system to allow for recharge of the treated water.

The design of a drainage system depends upon the drainage characteristics of the soil, the extent to which drainage is needed, and the length of time the system will be in operation. Drainage capabilities of the soil depend on soil permeability, consolidation, and shrinkage (Sowers, 1968). Figure 2-20 illustrates a drainage layout system.

The filter is a porous material which prevents movement of the soil into the drains but is sufficiently impervious to offer little resistance to seepage. Filters are generally designed to restrain only the coarsest 15 percent of the soil. As the coarse sands collect over the filter openings, their voids in turn will create smaller openings to trap even smaller soil paricles.

The collector system is designed to carry water away from the site and consists of trenches and/or pipes which, to allow for silting, are usually several times larger than hydraulic factors dictate. As Figure 2-20 indicates, the collectors may be located at three positions along the site.

1) Drains may be located upgradient of the site so that they intercept water before it reaches the site. This is especially effective when the groundwater surface slopes steeply.



Source: Sowers, 1980

Figure 2-20 Drainage Layout System

2) Drains located around the perimeter of the site can be used to remove water directly from the area.

3) Drains located hydraulically downgradient of the site will allow water to leave the site more rapidly. These are most effective when an underground obstruction dams up the flow of groundwater or leachate (Sowers, 1968).

In some instances drains may be required in only one location, while at other sites those at all three locations may be required.

The simplest and most economical collector system is a gravel trench. These should be constructed by excavating the trench, lining it with synthetic fabric, backfilling with gravel, lapping the fabric over the gravel, and backfilling the rest with soil. The fabric serves as a filter to keep fine soil materials from entering the gravel and clogging the drainage system (Linsley, 1979)

In some instances, unlined trenches or ditches may be used, but these structures are not considered permanent. Several precautions should be taken to limit scour, especially when the ditches are unlined. At the junction of two or more ditches, the ditch bottoms should be at the same elevation to avoid drops which may cause scour. Scour will also occur at sharp changes in ditch alignment; long-radius curves should be used where a change in line is needed.

Where a permanent drain is desired, perforated pipe or open jointed tile should be laid in the trench, which is then backfilled with filter

material. Typical collector pipe perforations are 5/16 - 3/8 inch in diameter and require a filter with a maximum size of 1/2 inch (Sowers, 1968). Pipes are generally a minimum of 4 to 6 inches in diameter to minimize the likelihood of clogging with sediments, roots, or other materials (Linsley, 1979).

The last feature of the drainage system is a basin, sump or pit which allows the collected water to be removed from the site and disposed of. This water will be contaminated if the collector system drains runoff and infiltrate from the disposal site or lowers the groundwater level. Under these conditions the water will be collected in a sump and routed to a leachate treatment system.

In instances where the disposal site is covered and runoff is not contaminated, or where the collectors are located hydraulically upgradient of the site, the collected water may be recharged to the aquifer downgradient of the site without treatment. Recharge or seepage basins are generally suitable for aquifer recharge. The major considerations in the design of these basins are the depth to the water-bearing sands and the volume of water which must be recharged. In general, the recharge system consists of the basin, a sediment trap, and an emergency overflow or by-pass for excess runoff (Tourbier, 1974). Seepage pits, designed for areas where depth to groundwater is greater than 4 feet, are suitable for soils where permeability is greater than 0.15 ft/day. The pit is constructed by lining the bottom and edges with coarse sand or fine gravel and backfilling the pit with aggregate. Figure 2-21 illustrates a seepage pit. Alternatively, a seepage basin may be used. The dimensions for a seepage basin can vary considerably, but the basin is usually designed for large volumes of runoff. A considerable amount of recharge can occur through the sides of the basin, and it is preferable that the sides be constructed of pervious material. Gabions make ideal sidewalls. Infiltration can be improved by spreading 2 inches of coarse sand over the base. Figure 2-22 depicts a seepage basin. An alternative design for a seepage basin, shown in Figure 2-23, is suitable for areas where the aquifer is so shallow that the basin extends to the strata overlying the aquifer. Dense turf should be planted on the side slopes, and infiltration can be improved by constructing gravel-filled trench drains in the basin floor.

2.3.5 Surface Grading and Planting

Landfill slopes must be graded to enhance runoff while minimizing erosion. The final grade of a landfill should be sufficient to prevent water from pooling over the surface (a minimum slope, including terraces, of 2% is recommended), but should not exceed 30%. By judicious design of landfill surface gradients and careful selection of soil type, thickness, and vegetation, infiltration can be minimized and often precluded.

In constructing final slopes, clay or clayey silt soils are preferred due to their resistance to erosion and infiltration. Sandier soils erode more quickly and allow greater infiltration into the landfill.

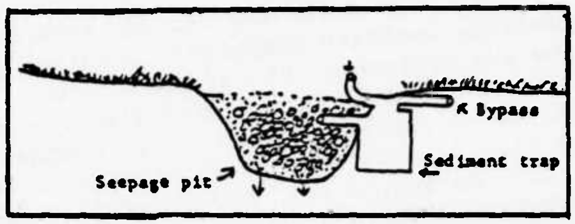


Figure 2-21 Seepage Pit

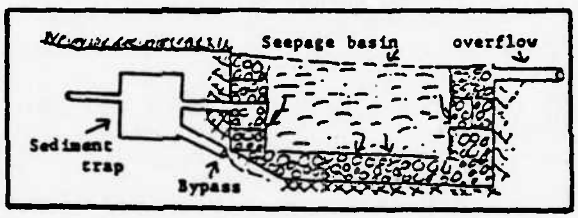


Figure 2-22 Seepage Basin; large volume, deep depth to groundwater

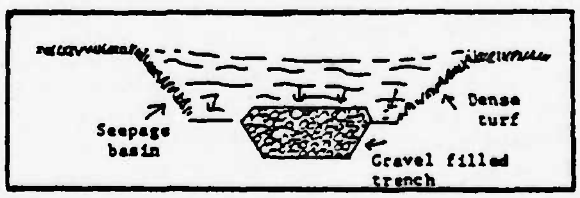


Figure 2-23 Seepage Basin; shallow depth to groundwater

Additionally, final landfill slopes and surfaces should be planted with suitable grasses both to increase evapotranspiration and to decrease erosion.

2.3.6 Surface Capping

Where clay soils are scarce, another approach to preventing or minimizing leachate production involves placing a liner on or just below the surface of the disposal site. Surface lining or capping can be achieved by clay, bentonite, or a synthetic membrane. Once a membrane is placed, it must be maintained to protect its integrity. If a clay is selected, it should have a permeability no greater than 1×10^{-6} cm/sec; a soil should have a liquid limit of at least 30 and a plasticity index of at least 15. Surface lining is a new concept that has received limited use.

In selecting natural or synthetic materials to seal or cap the surface, one should be aware of the limitations inherent in each material. Clay is subject to cracking as a result of drying out, settling, root decay, or root intrusion. On the other hand, synthetic barriers may be punctured or may fail due to faulty installation techniques, inferior product quality, or poor maintenance practices. Additional disadvantages of capping include the difficulty of constructing an even, gently sloping top surface free of depressions that can hold rainfall. Therefore, in selecting a liner material, it is imperative to understand the limitations of product quality and to follow proper installation and maintenance procedures. Each product should be evaluated for cost and compatibility with disposal operations. A listing of potential synthetic liner materials is presented in Section 2.3.8.

Three examples of surface capping to minimize infiltration are presented in Figure 2-24.

2.3.7 Sedimentation Ponds

If collected surface runoff from the landfill carries large amounts of silt, this material must be permitted to settle out before the runoff is discharged into a surface water body. This settling is carried out in holding or sedimentation ponds. A typical design for a sediment basin embankment is presented in Figure -25. Holding ponds should be designed by a professional engineer or hydrologist to provide sufficient capacity during storms when erosion may be most severe. Field manuals provided by regional offices of the U.S. Soil Conservation Service are helpful in determining the most effective erosion protection methods for individual locales.

2.3.8 Liners

In sites where leachate generation cannot be minimized to acceptable levels and the hydrogeologic conditions cannot minimize the impact of leachate to underlying groundwater, it may be necessary to totally contain leachate

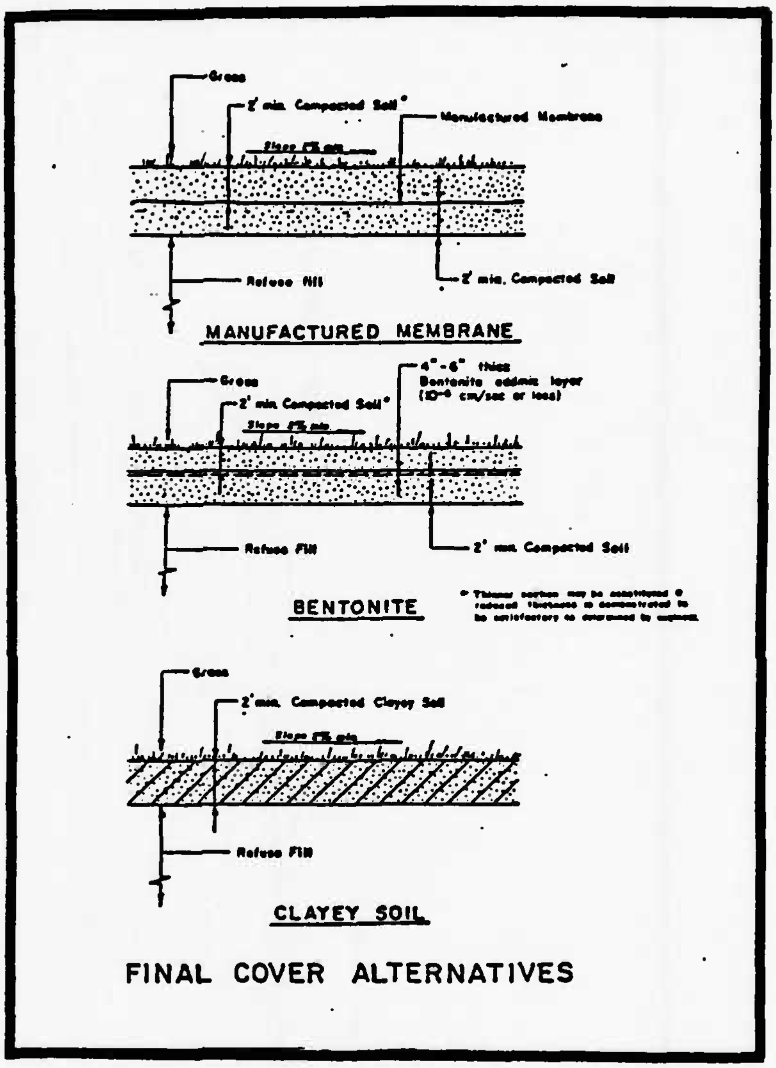


Figure 2-24 Surface Capping

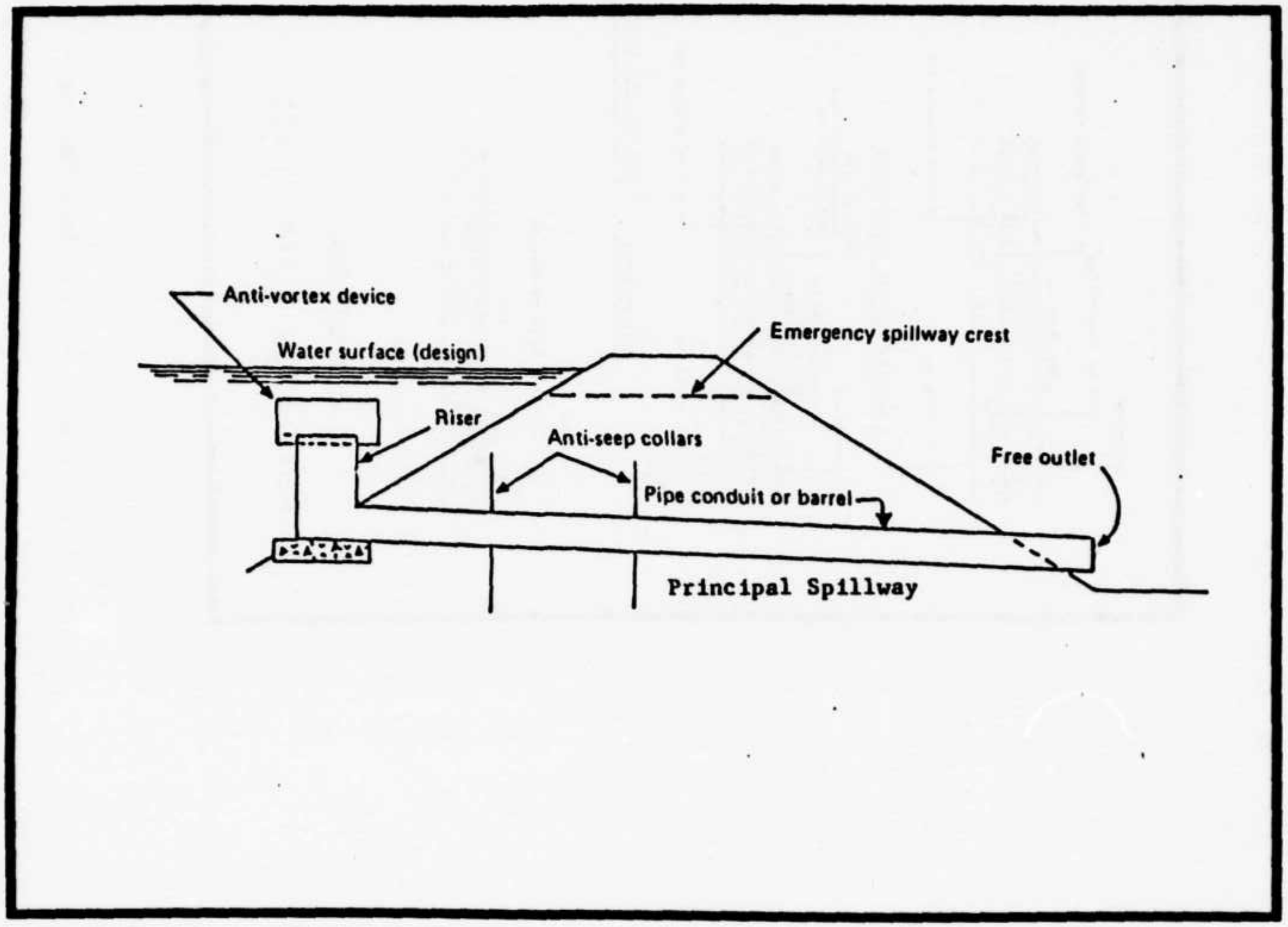


Figure 2-25 Typical Design of a Sediment Basin Embankment

within the landfill. Such an approach typically involves surrounding the refuse fill with an impervious barrier or liner, creating a basin to contain any leachate produced.

Liner materials used in containment of leachate within the landfill should have a permeability of 1 x 10^{-6} cm/sec or less and be able to resist physical and chemical attack by leachate. As a rule of thumb, the practicle minimum thickness for natural soil liners is 5 feet; for synthetic membrane liners, 20 mils. If synthetic liner materials are selected to contain the leachate, their installation must be carefully monitored.

Throughout history, clay soils have been used to impound and control water. Clays have been extensively used in this country for the impervious core in dams and as impervious liners in reservoirs. In the past decade, clays have seen wide application as impervious barriers in landfills and wastewater storage ponds. These soils must be properly placed and compacted in landfill applications and must exhibit a permeability no greater than 1 x 10^{-6} cm/sec after placement. Properly designed and placed, soil barriers provide a low-cost durable solution when suitable clayey soils are on or near the landfill site.

The absence of clayey soils at sites where impervious barriers were required led to the development of alternative membrane materials such as bentonite, asphalt, and synthetic membranes. Factors to consider in the selection of these barrier materials include: type of waste being disposed, compatability between waste and liner material, hydrogeologic site conditions, and cost.

Criteria for Liners

The liner material should be able to resist attack from chemicals and salts, ozone, ultraviolet radiation, soil bacteria, mold, fungus, and vegetation to which it will be exposed. It should have ample weather resistance to withstand the stresses associated with wetting and drying, freezing and thawing, and periodic shifts of the earth as dictated by the geologic character of the site.

A wide variety of synthetic materials are potentially useful for lining sanitary landfills. The list of materials being used or proposed as liners for disposal sites include conventional paving asphalts, hot sprayed asphalt, asphalt-sealed fabric, polyethylene (PE), polyvinyl chloride (PVC), butyl rubber, Hypalon, ethylene propylene diene monomer (EPDM), and chlorinated polyethylene (CPE). These materials have been used successfully in other similar applications. Many industries and communities pond various fluids in man-made reservoirs. When the natural soil is porous, the reservoirs can be made by installing an impervious liner. In some cases, the liner material has been designed to contain a specific fluid. Almost all of the above materials have been utilized at one or more land disposal sites (EPA/530/SW-B7, March, 1975).

Tentative Liner Test Results

Over the last 6 years, the U.S. Environmental Protection Agency has funded test programs in an attempt to determine the performance of various liner materials under both simulated laboratory and actual field conditions. Synthetic liner materials undergoing tests include (EPA-600/2-76-255, September 1976):

- Butyl rubber
- Chlorinated polyethylene (CPE)
- Chlorosulfonate polyethylene (hypalon)
- Ethylene propylene rubber (EPDM)
- Neoprene
- Polyethylene (PE)
- Polyvinyl chloride (PVC)

The initial results of an extensive laboratory test program are summarized in EPA-600/2-79-038, "Liner Materials Exposed to Municipal Solid Waste Leachate."

Tentative results of these tests indicate that changes in physical properties generally followed swelling due to leachate absorption. Those specimens that swelled little changed relatively little in physical properties. The materials that exhibited significant drops in tensile strength during the exposure period (materials that swelled the most) were neoprene, chlorinated polyethylene, and chlorosulfonated polyethylene. The polyolefins showed little loss in tensile strength.

To date, findings from these initial studies suggest that a general decrease in hardness and modulus of the liners occurs during exposure, but some materials exhibit increases in these parameters, for instance, the ethylene propylene rubber and some specimens of chlorinated polyethylene and chlorosulfonated polyethylene.

Overall, the polyolefins and polyvinyl chloride materials changed the least during an 8-month leachate immersion period. The polyvinyl chloride membranes as a group degraded the least during this time period, and neoprene and ethylene propylene rubber deteriorated the most.

In general, the materials tested fell into three groups with regard to swelling or leachate absorption during the 8 months:

1. Those with the greatest leachate absorption, which included chlorosulfonated polyethylene and chlorinated polyethylene (13 to 19% and 8 to 10% absorption, respectively). Neoprene and ethylene propylene rubber ranged from low to high absorption (1 to 19% and 1 to 13.5%, respectively).

2. Those with low leachate absorption, which included the polyolefins, plasticized polyolefin, and polybutylene (0.1%), and polyethylene.

3. Those with relatively low leachate absorption, which included polyvinyl chloride (1 to 3%), polyester (2%), and butyl rubber (1 to 2%).

The membrane liner of polyvinyl chloride plus pitch swelled 6%.

Although the findings summarized above are not conclusive, they provide the basis for tentative liner evaluation criteria. Current research in assessing the performance of liners--including field testing of liner samples extracted from beneath active landfills--is expected to enhance knowledge of liner technology.

The most useful tool in selecting a synthetic liner material will be a state-of-the-art document to be published by the U.S. EPA in mid-1980 entitled "Lining of Waste Impoundments and Disposal Facilities." This manual will discuss in detail the applicability and design criteria of the various liner materials available for landfill use. Several conceptual liner designs are illustrated on Figure 2-26.

<u>Liner Operating Life</u>

In general, literature and manufacturer representatives indicate that liners should exhibit a safe operating life of at least 20 years in landfill applications. The required liner operating life is a site-specific parameter. Landfills in wet areas will probably be fully decomposed within 20-years; whereas a landfill in a semi-arid region may be still decomposing after 50 years. These synthetic materials have not been in use in landfill applications long enough to have demonstrated their extended service life. However, accelerated aging and performance tests performed by manufacturers have long been used by industry and government to predict the performance of materials. Current studies being done for EPA concerning various lining materials exposed to landfill leachate are providing an expanding base of data for selection of lining material.

The use of an asphalt membrane as a containment barrier at the base of the landfill complies with specifications and practices adopted by the Department of Environmental Resources, State of Pennsylvania. Asphalt liners are currently being used at several landfill sites in Pennsylvania.

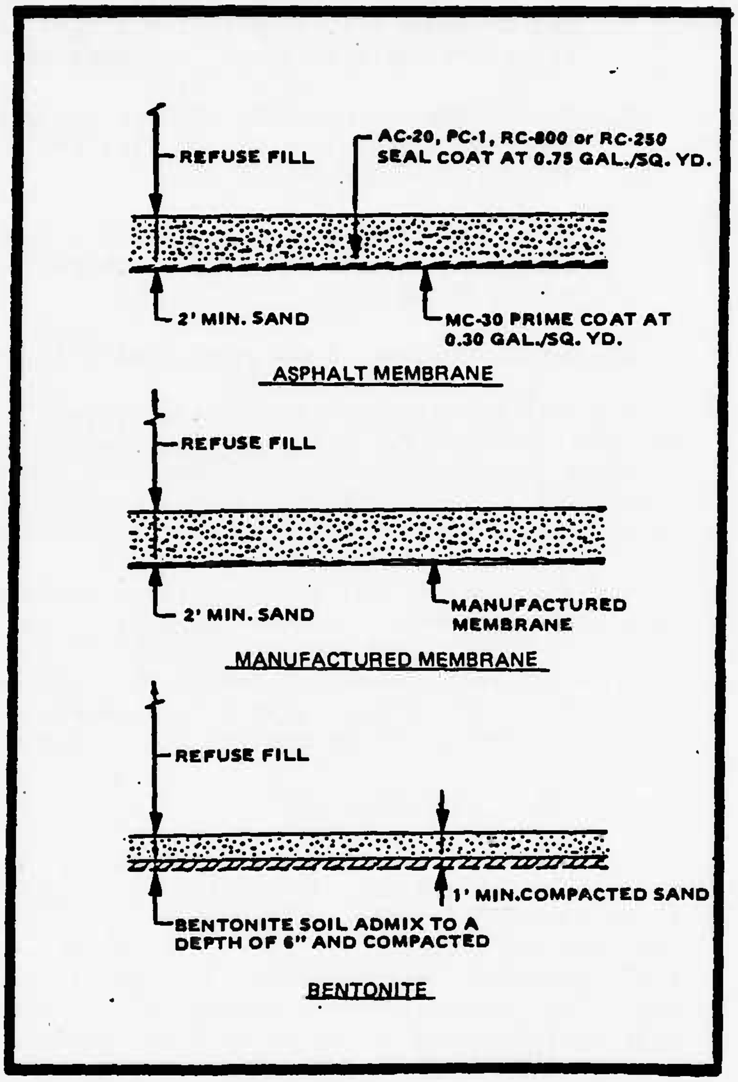


Figure 2-26 Base of Landfill Alternatives

Liner Placement

The liner material should be placed on a carefully prepared base of selected material that will prevent liner puncture while providing uniform, relatively nonyielding support. In addition, the liner should be covered with suitable material that will protect it from damage and, where it serves as a base barrier, provide a drainage blanket for the leachate collection system. As a rule of thumb, a soil layer about 2 feet thick is effective in protecting a liner from puncture.

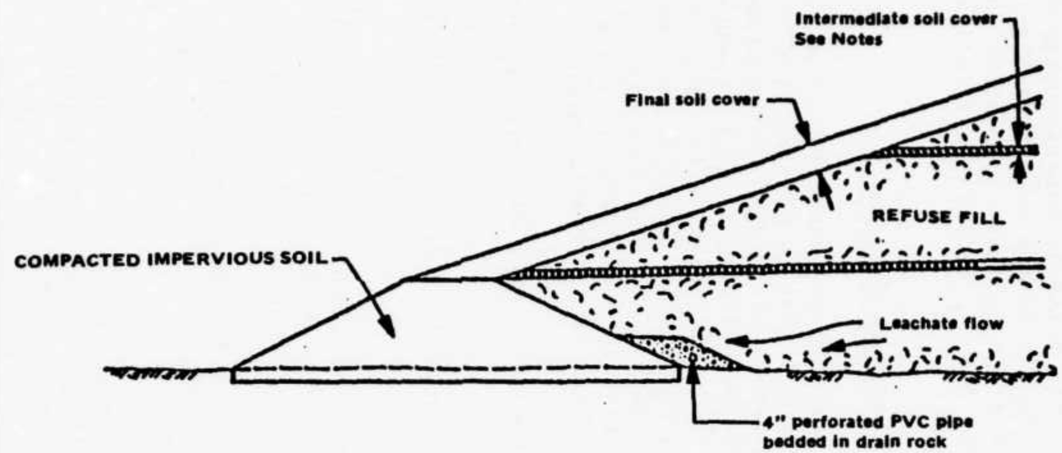
2.3.9 Control of Leachate Seepage

If leachate forms in the landfill, it may eventually exit on fill slopes, posing a threat to adjacent surface water bodies. Leachate seeps on slopes are caused when surface water infiltrates the cover soil, migrates downward until it encounters a less permeable intermediate soil layer or refuse lift, and then moves laterally until it seeps through a thin and/or loose slope cover soil. Slope seeps can be avoided if leachate is prevented from forming, but not all sites are amenable to this solution. Leachate seeps can be controlled effectively by the following series of steps:

- Removing the cover soil and several feet of refuse in the seep area
- Placing a permeable layer of material to intercept the seepage
- Installing a collector pipe in a trench from the seep area down the slope to a toe collection header or sump, where the leachate can be adequately managed
- Replacing the cover soil over the permeable material and trench and using a filter fabric between the cover soil and permeable material.

If a series of seeps develops an extensive collection/discharge system may be required. Figure 2-27 illustrates the construction of a leachate interceptor system.

Another technique which has received limited use and minimizes leachate seeps is to slope the intermediate cover soil surface downward and inward from the perimeter of the landfill. Water reaching the intermediate cover soil then flows into the refuse and not toward the slope. As new refuse lifts progress, the intermediate cover soil can be removed or scarified within 50 feet of perimeter slopes to break up its continuity, thus allowing leachate to continue vertical migration rather than be diverted laterally to perimeter slopes (see Figure 2-27).



NOTE:

Remove intermediate soil cover from a 50' wide strip on each refuse lift adjacent to final perimeter slopes in advance of placing the subsequent refuse lift.

Figure 2-27 Leachate Interceptor System

2.4 GROUNDWATER

The major threat to groundwater from solid waste disposal is contamination by leachate (water polluted by passage through wastes). Since groundwater is the drinking water source for at least 50% of the population of the United States, its protection from contamination by solid waste disposal is imperative. To implement the Federal criterion for groundwater (prevent contamination of an underground drinking water source beyond the solid waste boundary), adverse impacts caused by leachate must be prevented or minimized by one or more of the following methods:

- Control of leachate production
- Containment of leachate within the landfill (followed by subsequent withdrawal and treatment
- Treatment of leachate and/or its impact on the environment

In evaluating the need for groundwater protection technologies, it is helpful to have an estimate of the amount of leachate generated by the facility. To do this, information on the amounts of water infiltrating and leaving the fill must be collected and analyzed. One of the most promising tools for assessing the control of landfill infiltration is the water balance equation employed by the Environmental Protection Agency (document reference EPA/530/SW-167, October 1975). As illustrated in Figure 2-28 the water balance method quantifies the relationship between precipitation, surface runoff, soil moisture storage, and evapotranspiration. It assesses the remaining soil moisture within the vegetated soil profile by accounting for increases (from precipitation) and decreases (from evapotranspiration) on a monthly basis. These calculations are specific to the meteorological and soil cover conditions at a given landfill. Such an accounting is key to leachate control, since soil moisture in excess of field capacity (moisture content retained by soil in gravitational field) percolates downward into the wastes, potentially forming leachate.

The water balance equation allows landfill operators to assess the effectiveness of various design alternatives in controlling leachate generation. By increasing several of the water balance variables, leachate generation can be minimized. The variables that can be readily increased to reduce infiltration of water into refuse include surface runoff, soil moisture storage, and evapotranspiration. Surface runoff can be enhanced by increasing drainage gradients, selecting a less permeable cover soil, using a thicker and denser cover soil, utilizing synthetic membranes, adding soil conditioners (chemicals, bentonite, etc.) to render the existing cover soil less permeable, and implementing a good maintenance program for graded surfaces. Like surface runoff, soil moisture storage can be increased by using

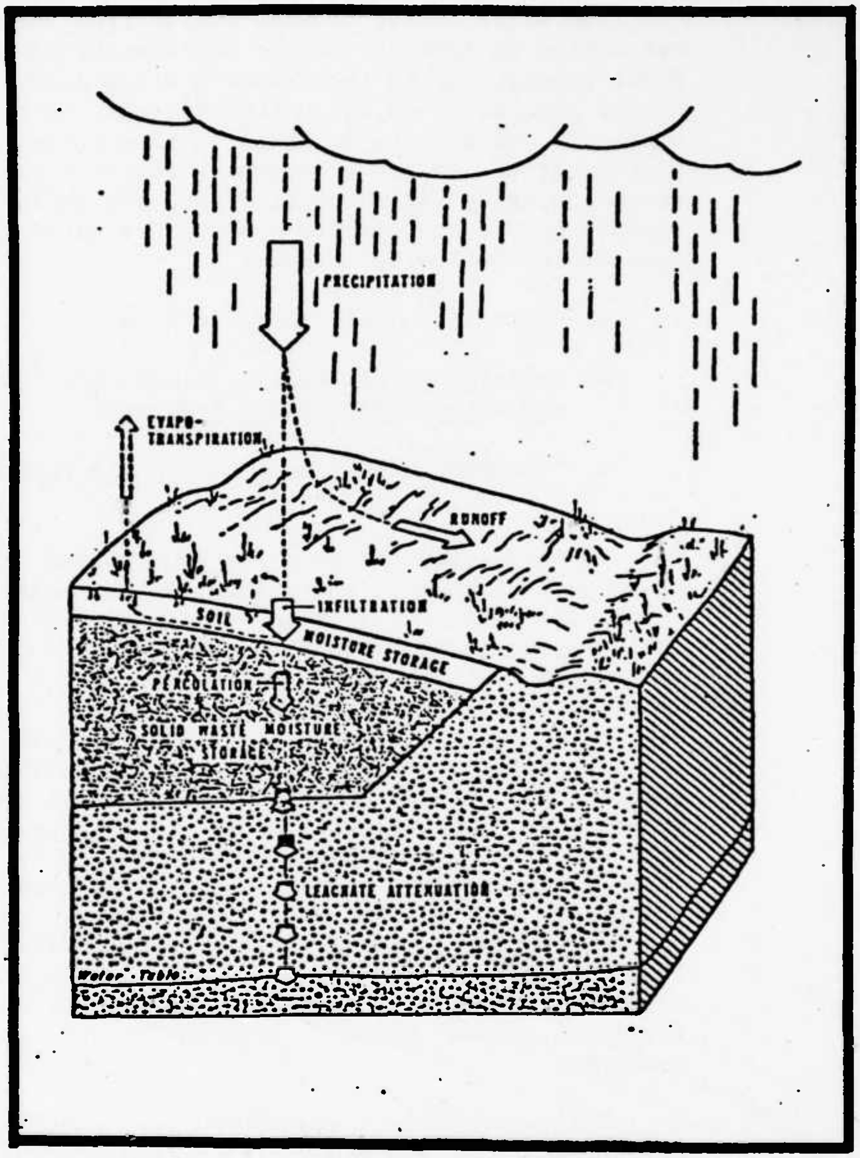


Figure 2-28 Landfill Water Balance

thicker cover soil and by employing a silt and clay cover. Selecting highly evapotranspirative vegetation that is tolerant to landfill conditions enhances evapotranspiration. These techniques for controlling surface infiltration are widely used.

Techniques useful in minimizing leachate generation were discussed in Section 2.3, Surface Water. The technologies included:

- Ditches, diversions, waterways
- Terraces and benches
- Chutes and downdrains
- Drainage systems
- Surface grading
- Surface capping
- Liners.

In this section additional technologies to minimize the impact of landfill operations on groundwater quality will be discussed. These techniques include the following:

- Trenches
- Grouting
- Subsurface drains and dewatering systems
- Leachate collection systems
- Leachate treatment.

The first two of these technologies are subsurface infiltration barriers or passive groundwater control measures designed either to prevent groundwater from flowing through the landfill and generating leachate, or to control the movement of leachate away from the landfill. Hydraulic barriers that can be used at landfills include slurry or clay-filled trenches, grout curtains, and impermeable seals along landfill excavations. The last measures are for mitigating the impact of leachate generated.

2.4.1 Trenches

Slurry and clay-filled trenches are used in areas of completed landfilling where depth of low-permeability soils is relatively low, typically less than 20 feet (see Figure 2-29). Compacted clay or synthetic liners are typically used in new landfill areas where they

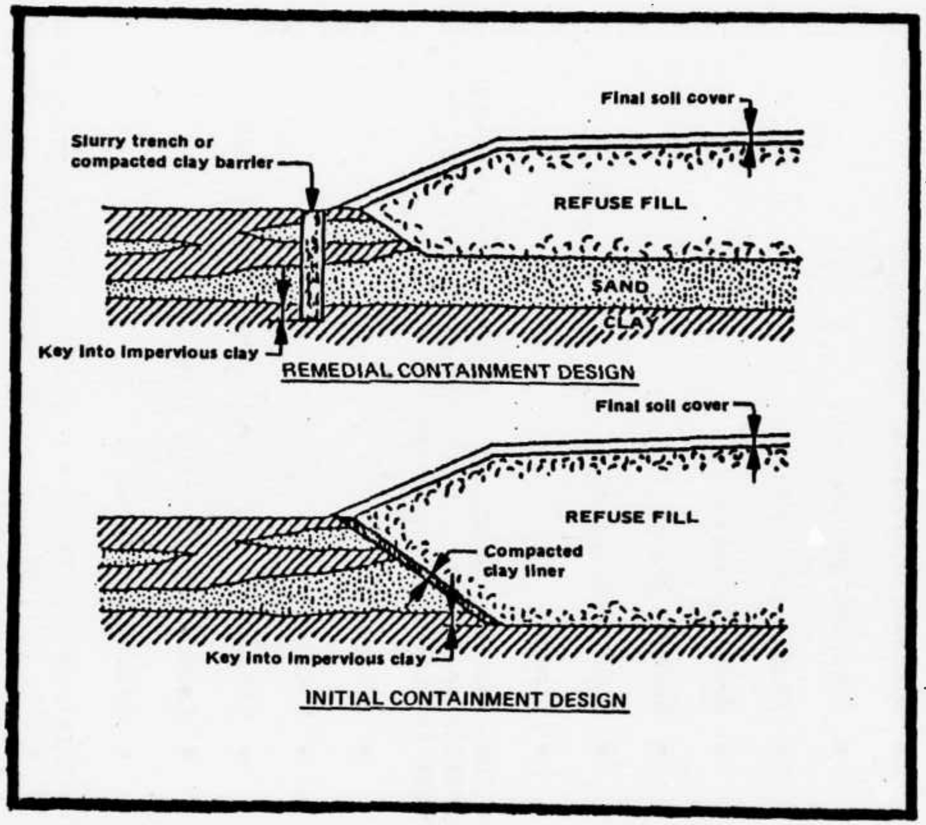


Figure 2-29 Groundwater Containment Design

can be placed at time of excavation. (A description of liner materials is presented later in this section.) Slurry trenches are constructed by excavating a trench into which a bentonite slurry is pumped. The slurry serves both to stabilize the trench walls and to ultimately form an impermeable barrier to leachate or groundwater migration. Trenches can also be backfilled with low-permeability clay if available on the site. Clay should be compacted in lifts no greater than 18 inches thick. In excavating for new areas within the fill, a similar containment can be realized by leaving a backslope in the fill and surfacing this slope with impermeable clay.

2.4.2 Grouting

Grouting has been used to a limited extent in landfills to decrease soil/rock permeability and to seal large voids. These objectives are generally achieved by one of the following three methods:

- Area Grouting - Low pressure blanket or area grouting performed to seal and consolidate soils near the surface
- High-Pressure Grouting - Grouting at depth to seal fissures or small void spaces under high overburden
- Contact Grouting - Injection of a slurry at the outer surface of an excavation to seal possible passages for water flow (a relatively complex, costly method--as yet unproven in landfills).

Because of the difficulty in selecting the most beneficial method, it is imperative to evaluate the hydrogeologic conditions prior to constructing the grouting system. A thorough understanding of soil stratification and rock fissure patterns is essential prior to selecting a grouting technique. In addition, comparative costs and complexity of construction should be assessed. Alternative approaches to grouting are discussed in the Naval Design Manual, Soil Mechanics, Foundations, and Earth Structures: NAVFAC DM-7, 1971. Prior to implementing a grouting program, an expert in the field should be consulted.

Grouting materials fall into three groups—cement, bituminous, and chemical. Specific grout mixtures include portland cement, sand-cement, clay-cement, clay-bentonite, bituminous emulsions, sodium silicate, acrylamide methylene bisacrylamide, and chrome lignin. Applicability of each material is based on grain size or fissure, and thickness of the geologic formation. A thorough subsurface investigation, including coring of fractured rock, must precede the design of any grouting program.

Portland cement is the most common grouting material for decreasing permeability. Fissures of about 0.06 to 0.01 mm can be sealed by cement grouting, depending on injection pressures, water-cement ratio, and cement type. Clay-bentonite grouting—also commonly used to decrease permeability—is relatively inexpensive, and, unlike cement grouting, it is capable of effectively penetrating fine sand. On the other hand, clay grouting may be removed by vigorous groundwater flow and high hydrostatic pressure.

To overcome the difficulty of sealing small cracks which are too fine to be entered by cement or clay particles, chemical grouts have been developed. Although chemical grouts can be highly effective in sealing small rock joints, they cannot be depended on to control seepage through soils, especially silts and fine sands.

Grout curtains are emplaced by forcing a thin cement grout through tubes which are driven deep into the ground on closely spaced centers (2 to 10 feet). Grout curtains are used primarily in areas of fractured rock and deep groundwater. They have been used in sanitary landfills to only a limited extent. Figures 2-30, 2-31, and 2-32 depict grout curtain patterns and an upgradient application.

Grout curtains, because of their relatively high cost, are not the method of choice for groundwater control when a less expensive method, such as a slurry wall, is practical. Grouts are, however, the most practical and efficient method for sealing fissures, solution channels, and other voids in rock. In cases where rock voids are transporting large volumes of water, a grout can be formulated to set rapidly and shut off the flow. In theory, it is possible to place a grout curtain upgrade, downgrape, or beneath a waste site.

As with slurry walls, placing a grout curtain up the groundwater gradient from a waste site can redirect the flow so that groundwater no longer flows through the wastes that are creating leachate. Given a normal range of groundwater chemistry, most grouts could be expected to function well in this application.

Placement of a grout curtain downgrade from, or beneath, a waste site is quite another matter. Problems could be expected when attempting to grout in the presence of leachate or extreme groundwater chemical conditions. In many instances it would be difficult or impossible to achieve a controlled set time and thus form a curtain of reliable integrity. Little was found in the literature on the resistance of grouts to chemical attack. In many instances, no research has been done. Should a case arise where grout must contact leachate or groundwater with extreme chemical characteristics, extensive tests would have to be conducted. On the basis of the composition of the grouts listed above, Portland cement, bentonite, and silicate grouts would be expected to provide the greatest resistance to chemical attack, while the remainder might provide very little resistance. Additional problems occur in attempting to grout a horizontal curtain or layer beneath a

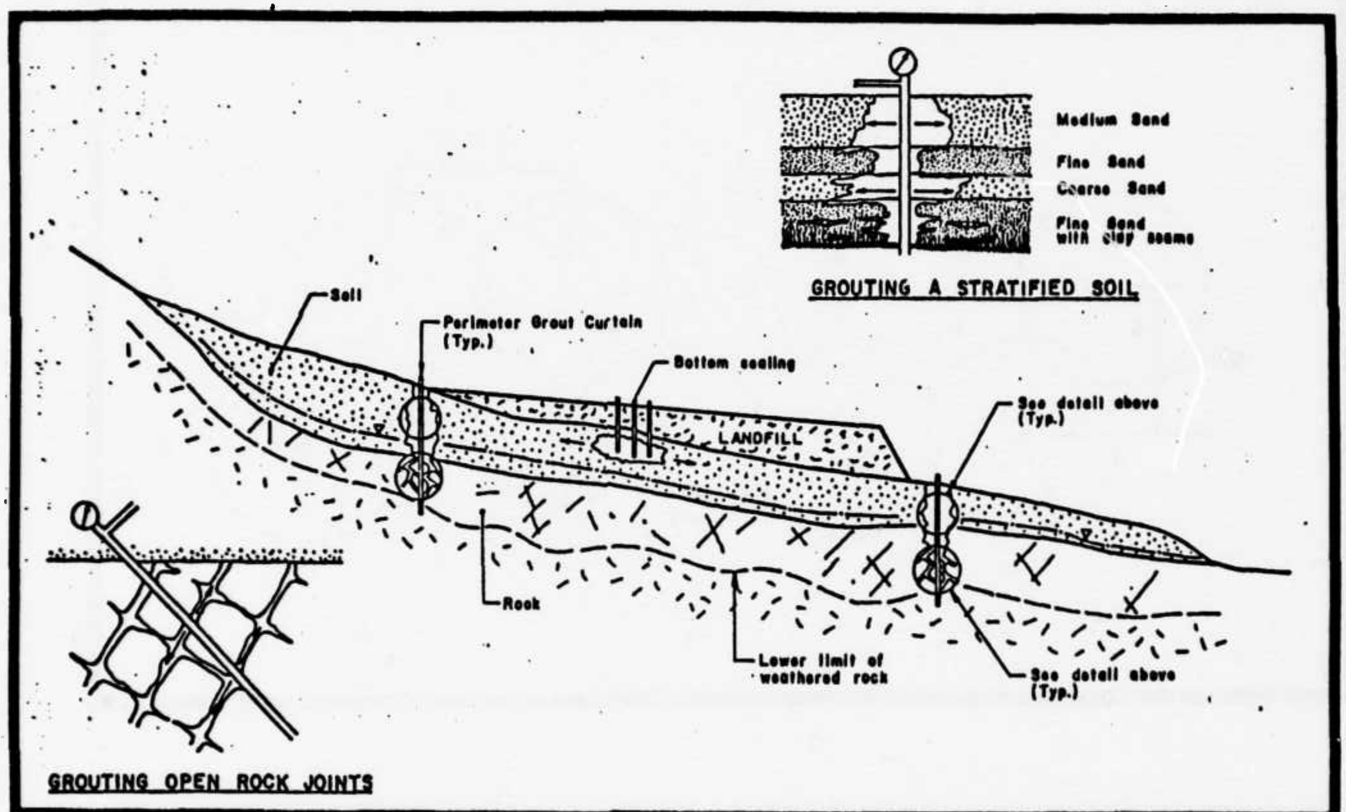


Figure 2-30 Grouting

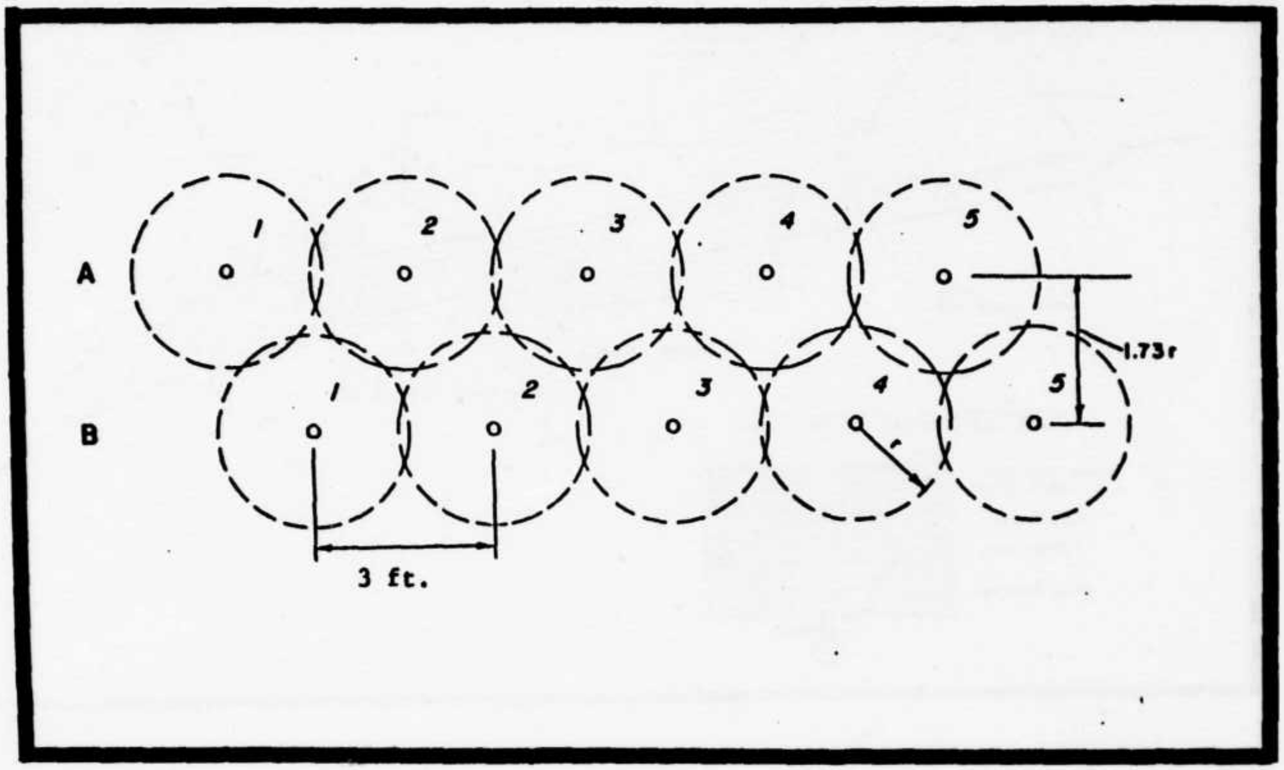


Figure 2-31. Typical two-row grid pattern for grout curtain.
From EPA, 1978

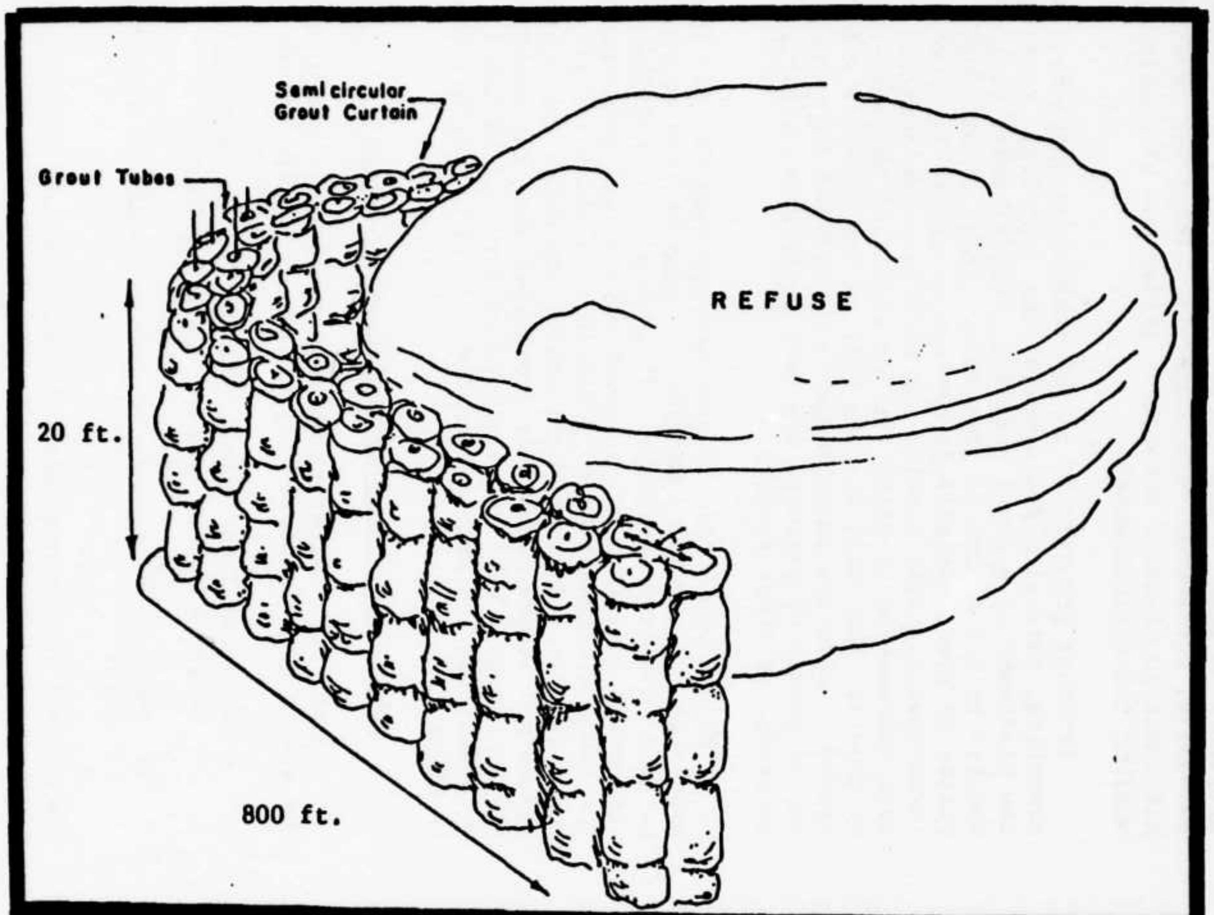


Figure 2-32 Semicurcular grout curtain around upgradient end of landfill.

(From EPA, 1978)

waste site. In order to inject grout in such a case, injection holes must be either drilled directionally from the site perimeter, or drilled down through the wastes. The first situation would be very expensive, the second very dangerous. In either case, it would be difficult to place an effective barrier and virtually impossible to monitor its effectiveness.

Pressure grouting is a high technology endeavor. As with slurry trenching, extensive geotechnical and hydrologic testing must precede the placement of a grout curtain. Initial tests will determine whether or not a site is groutable. Areas of extremely low permeability or great variability may not be groutable. Other tests and investigations will provide the necessary groundwater, rock, and soil information to allow for the choice of the best-suited grout or grouts. They will further provide the designer with the information needed to plan the pattern and procedure for injection. Other tests may be needed to evaluate leachate resistance, effectiveness of the grouting, or other factors.

The equipment used in pressure grouting is, for the most part, sophisticated specialty machinery. Much of this equipment is patented and/or proprietary. This machinery includes specialty drills for boring injection holes, grout mixers, and grout pumps. Often, the pumps are connected to a manifold to allow grouting of several holes at once. In nearly all cases, the pumps are equipped with gauges and meters to monitor grout pressures and amounts. As only a few contractors perform this type of work, it is likely that equipment mobilization fees associated with grout curtain installation will be high.

2.4.3 Subsurface Drains and Dewatering Systems

Active groundwater management systems are useful in mitigating the effect of a landfill on groundwater quality in two ways:

- They can lower a water table so that waste materials no longer directly contact the groundwater
- They can be used to collect contaminated leachate and groundwater.

The systems function by actively or passively collecting and removing groundwater at or below the level of the water table.

Three basic technologies are used to adjust water table height and extract leachate:

- Subsurface (French) drains
- Extraction wells
- Well point systems.

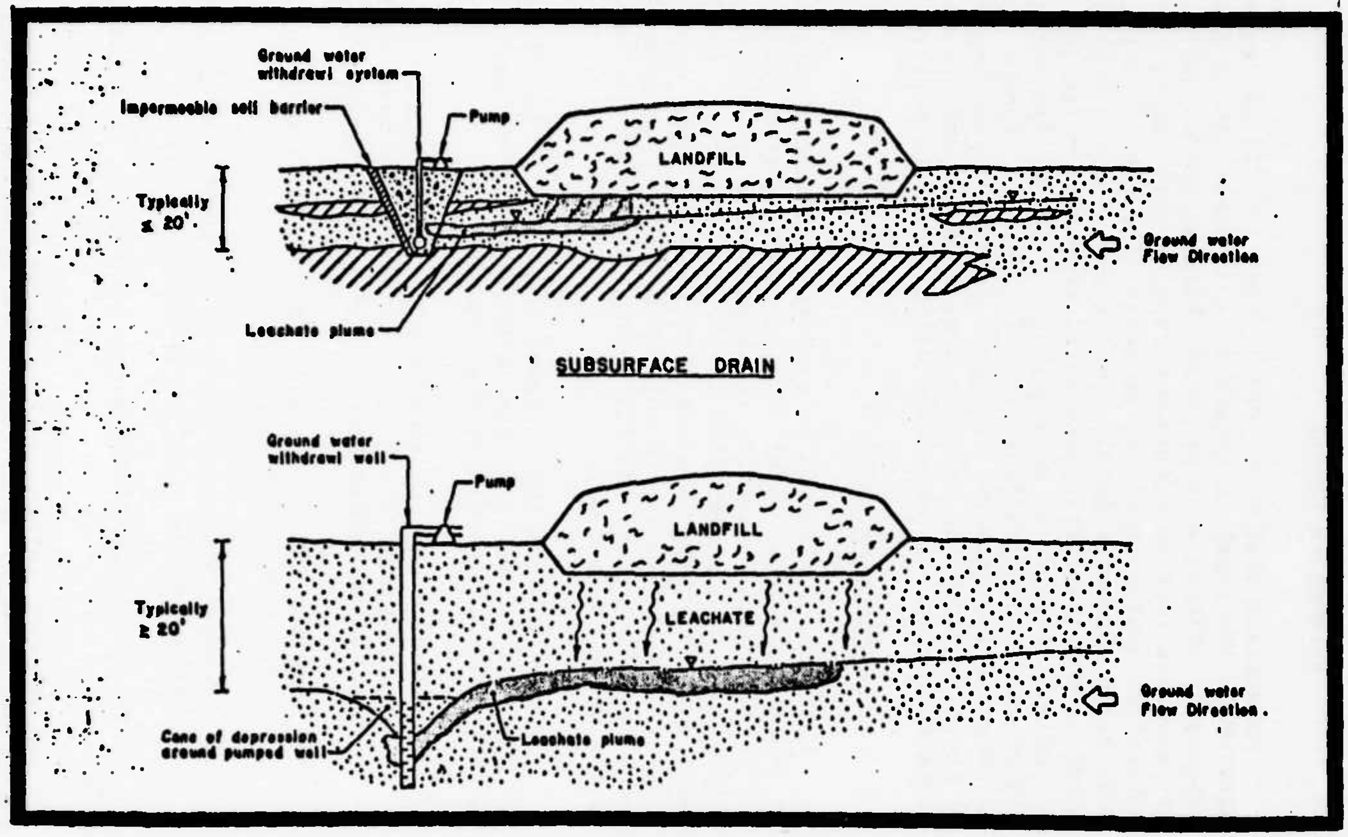


Figure 2-33 Active Ground Water Barrier Systems

These three technolgies are discussed below.

Subsurface Drains

Subsurface drains are mainly used to collect leachate from a site where the depth to groundwater is less than 20 feet. They are especially effective in areas of shallow perched water. Constructed of permeable rock in a trench extending into the groundwater table, subsurface drains should be at least five feet deeper than the lowest seasonal groundwater level. Drains are placed downgradient of the landfill to intercept contaminated groundwater leaving the landfill. If the soil profile is mainly sand, a clay or synthetic seal must be placed on the downgradient side of the drain trench. Contaminated groundwater is recovered from the drain by a pump and riser system. If the site perimeter is extensive, several pumpings will be required along the drain. A subsurface drain system is depicted in Figure 2-33.

Extraction Wells

Extraction wells may be used to collect contaminated leachate and to depress the groundwater level near or under a landfill. These wells may be developed separately or as part of a overall system, called a well-point system, described in the next section. Additionally, in cases where the wells are used for leachate plume control, extraction wells can be combined with injection wells to collect the desired leachate while minimizing the overall impact of groundwater pumping on the water table level.

Groundwater pumping to lower the water table may be suitable for remedial action for contaminated groundwater under several conditions. Specific applications include:

- Lowering an unconfined aquifer sufficiently that contaminated groundwater does not discharge to a receiving stream that is hydraulically connected

- Lowering the water table so that it is not in direct contact with the waste site

- Lowering the water table to prevent leaky aquifers from contaminating other aquifers.

These three applications are illustrated in Figures 2-34 through 2-36.

In general, well-point systems are used for lowering groundwater levels because they have a more uniform effect. Extraction wells are mainly used for plume containment. Applications in this area include the following:

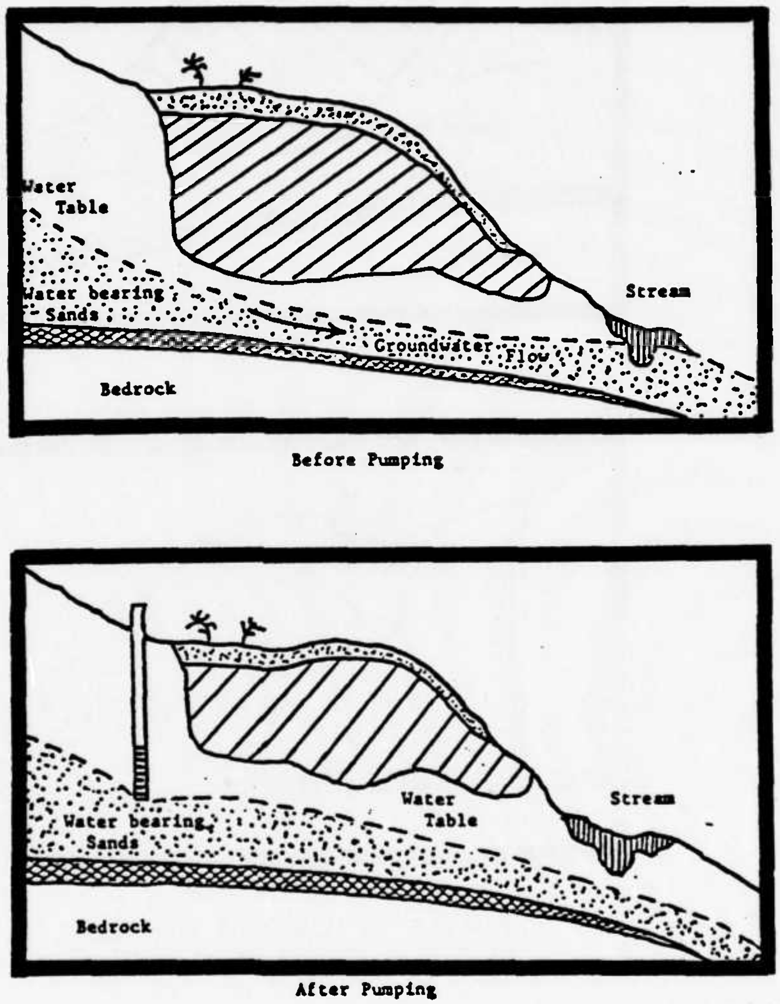


Figure 2-34 Lowering a Water Table to Prevent Stream Discharge of Contaminated Water

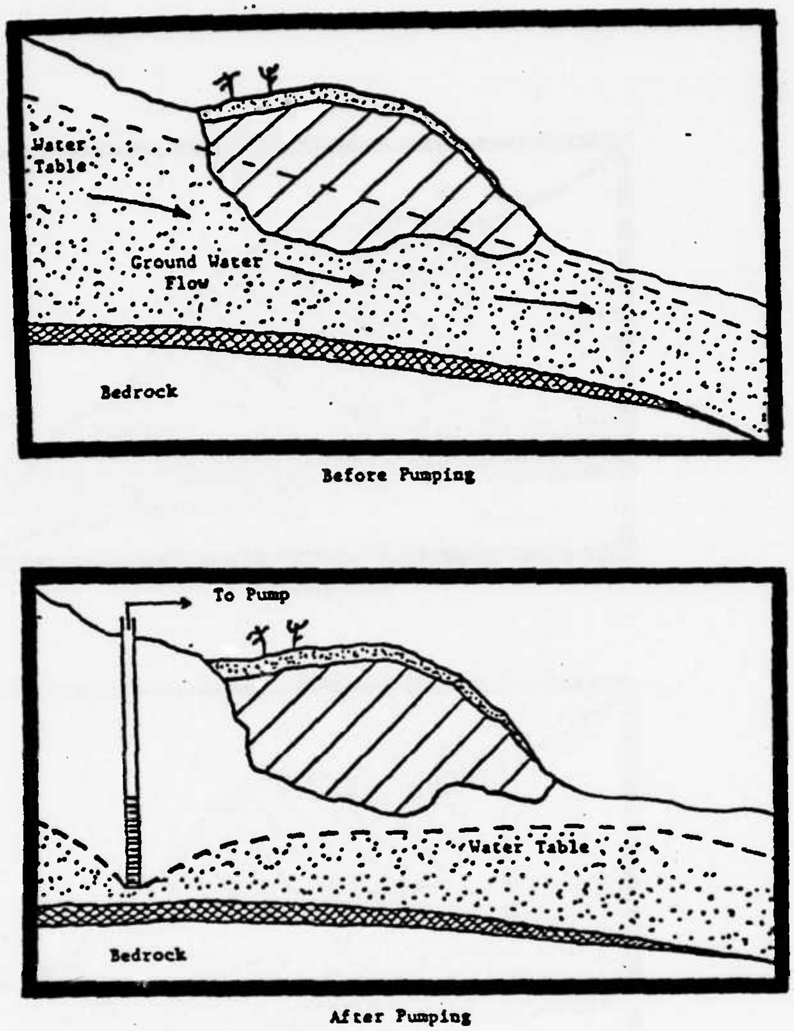
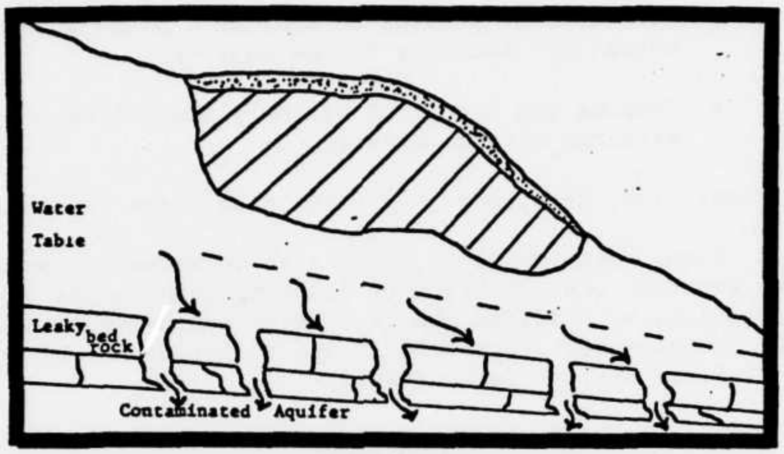
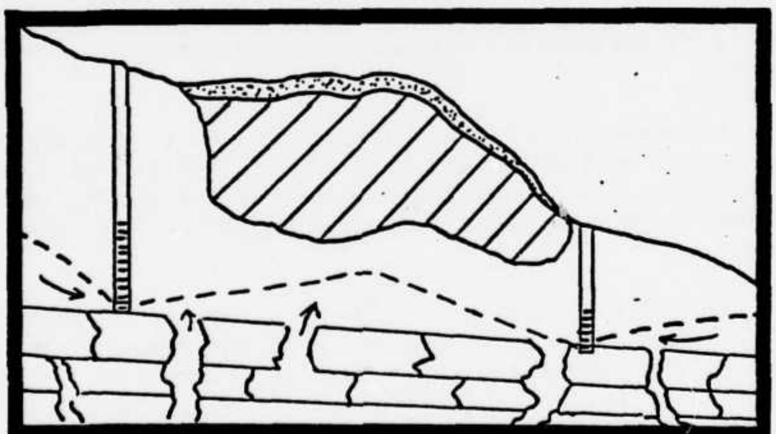


Figure 2-35 Lowering the Water Table to Eliminate Contact with a Disposal Site



Before Pumping



After Pumping

Figure 2-36 Lowering Water Table to Prevent Contamination of an Underlying Aquifer

- Use of a series of extraction and injection wells which allow water within the plume to be pumped, treated and pumped back into the aquifer

- Low rates of pumping to contain a plume with no subsequent recharge to the aquifer.

- Pumping and treatment of the plume followed by recharge through basins.

Figures 2-37, 2-38, and 2-39 illustrate these systems.

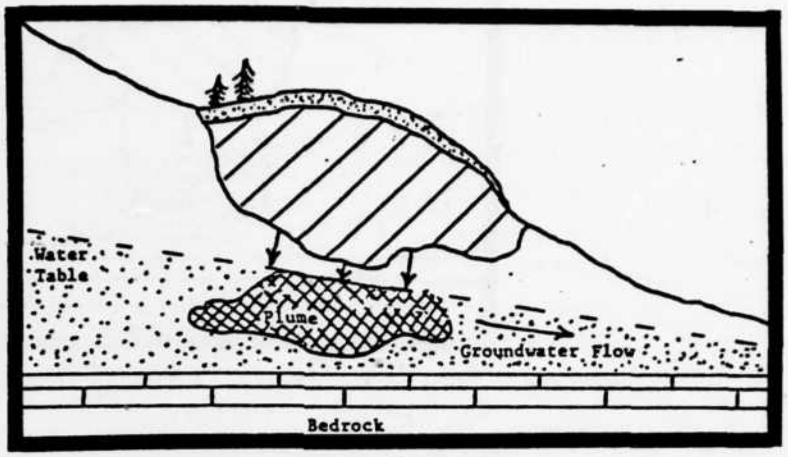
Plume containment by pumping is an effective means of preventing the eventual contamination of drinking water wells or the pollution of streams or confined aquifers which are hydraulically connected to the contaminated groundwater. The technique may be particularly useful for surface impoundments.

Pumping without subsequent recharge may be an acceptable approach when small quantities of groundwater are involved. However, when large groundwater flows are affected or when residents are dependent on groundwater as a drinking water source, recharge will be necessary. Pumping large volumes without subsequent recharge may lead to changes in the potentiometric surface or direction of flow within a confined aquifer.

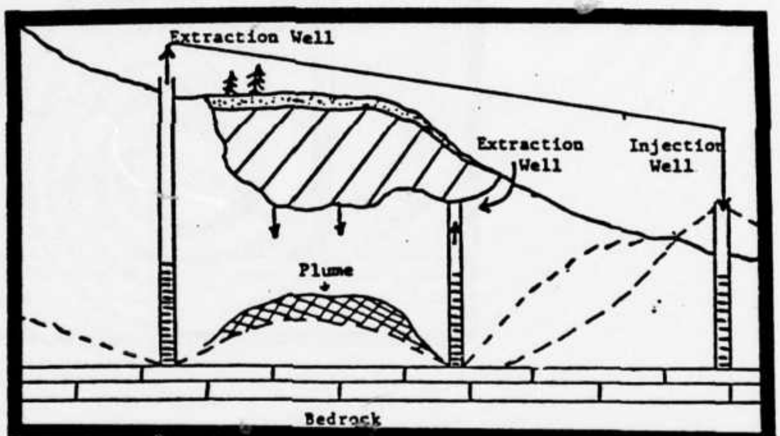
The theory behind containing a plume by pumping is based on incorporating the plume within the radius of influence of an extraction well. Such a system would require careful monitoring to determine the extent of the plume and any changes in the plume as pumping continues.

In order to design an effective extraction/injection well system, the effect of the injection wells on the drawdown and radius of influence of the extraction wells must be understood. Figure 2-40 illustrates how the injection well affects the drawdown and radius of influence. As the cone of depression expands and eventually encounters the cone of impression from the recharge well, both the rate of expansion of the cone and the rate of drawdown are slowed. With continued pumping, the cone of depression expands more slowly until the rate of recharge equals the rate of extraction, and the drawdown stabilizes. Thus the effect of the injection well is to narrow the radius of influence and to decrease the drawdown increasingly with increasing distance from the extraction well.

For a groundwater plume that is contained in the original radius of influence of the extraction well shown in Figure 2-40, the injection well, illustrated in the same figure, would have the following effects:



Before Pumping



After Pumping

Figure 2-37 Use of Extraction/Injection Wells for Plume Containment

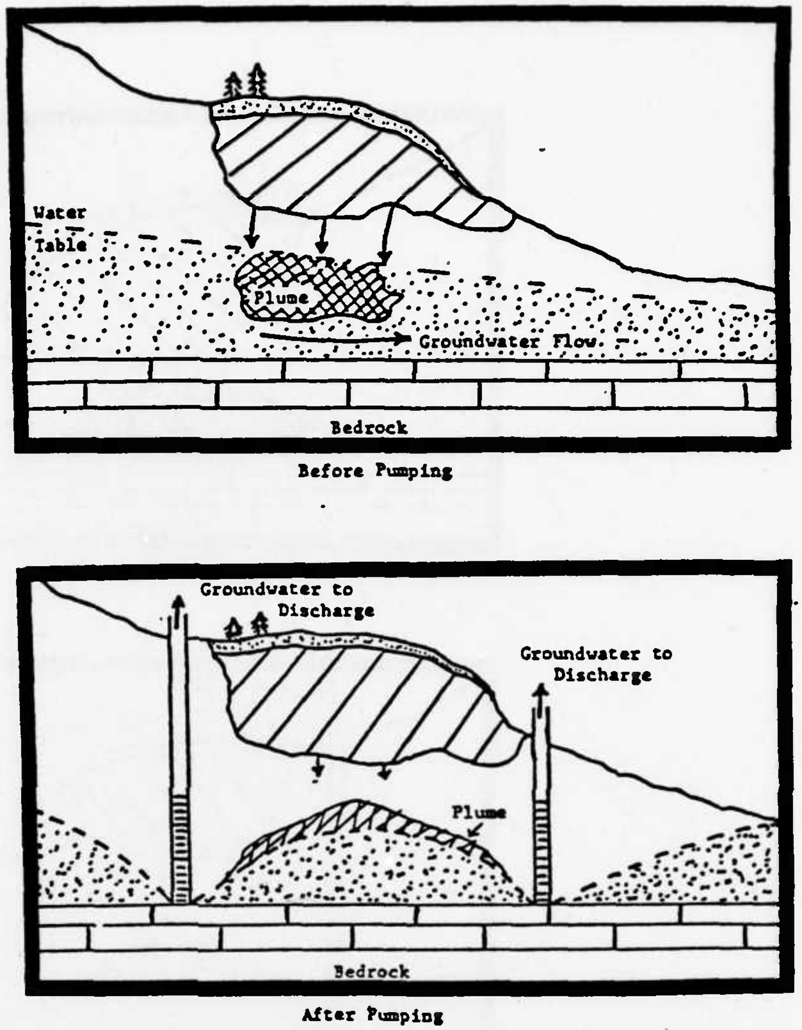


Figure 2-38 Groundwater Pumping to Contain Plume (No Recharge)

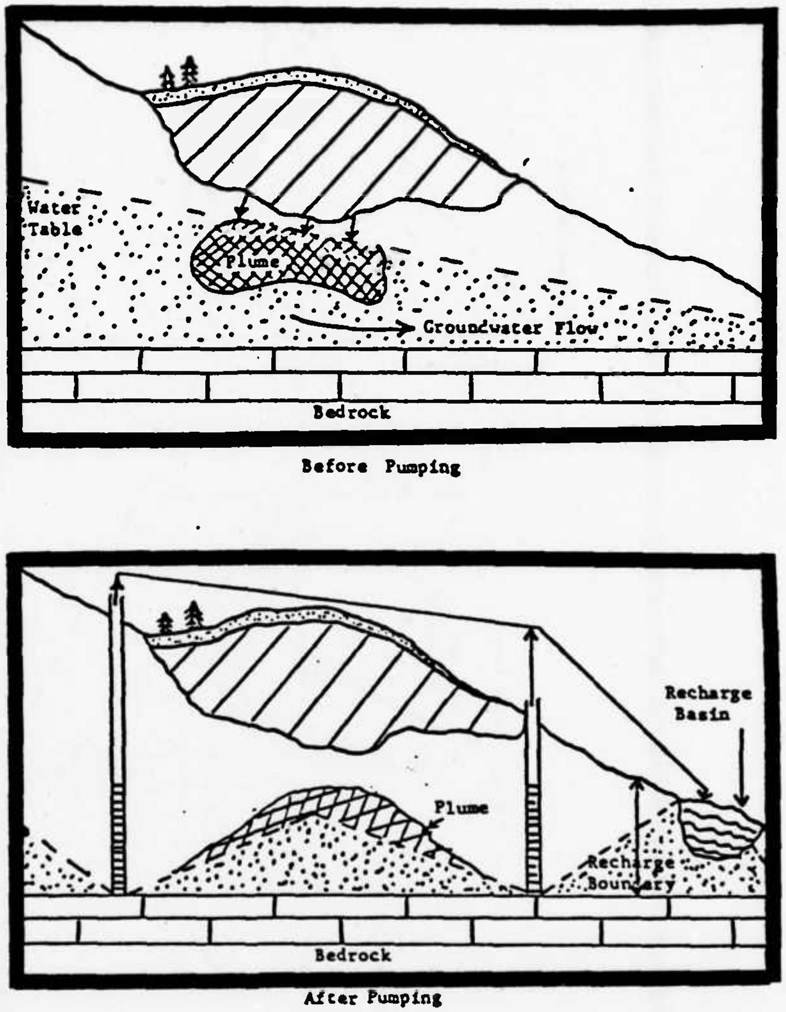


Figure 2-39 Use of Extraction Wells for Plume Containment Followed by Subsequent Recharge Through Seepage Basins

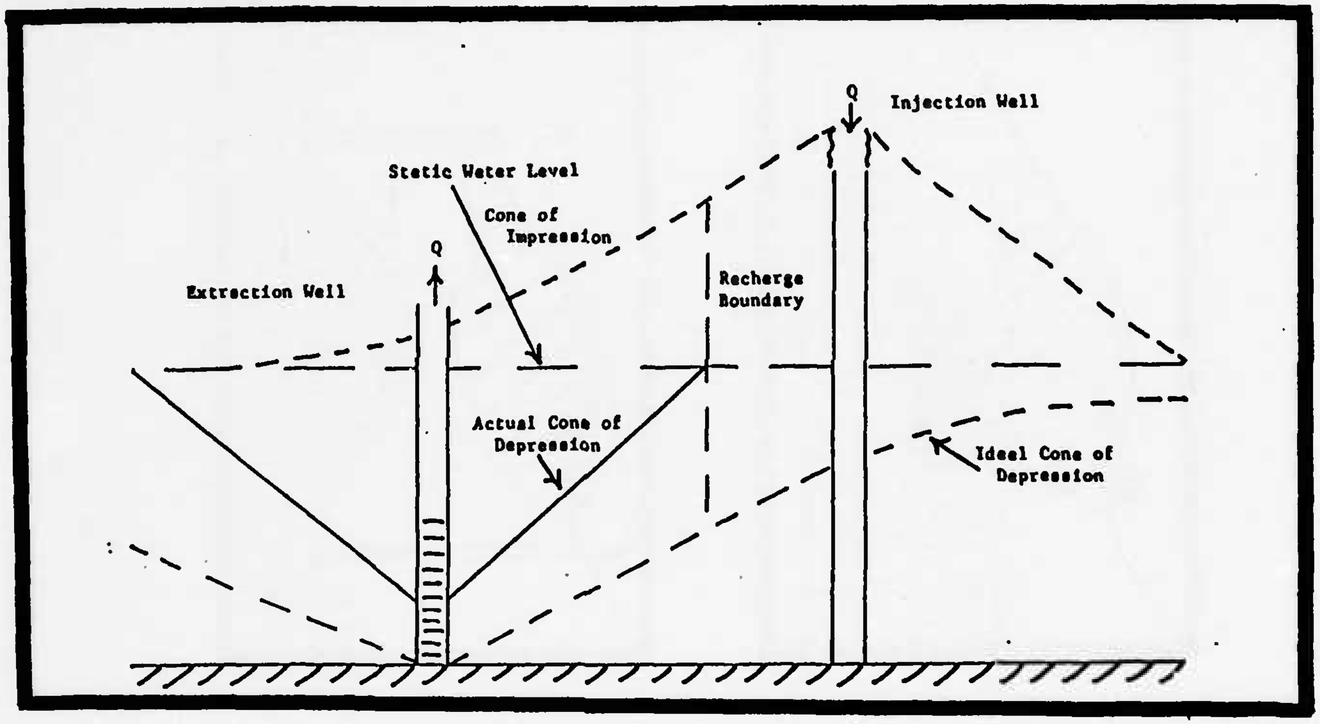


Figure 2-40 Effect of an Injection Well on the Cone of Depression

- It may reduce the radius of influence of the extraction well to the point where the entire plume may not be contained within the radius of influence.

- The increased pressure from the injection system will tend to move the plume toward the extraction well, thereby partly negating the effect of the decreased radius of influence.

- Treated groundwater discharged to the injection well will dilute the plume and will be continually recontaminated by that part of the plume which is outside of the actual radius of influence of the extraction well.

Because of the added pumping costs that would be incurred by continuously retreating water that is recontaminated by the plume, the extraction/injection well system should be designed so that the radii of influence do not overlap. Separating the radii of the wells is also important because overlaps would complicate future adjustments in pumping rates. These changes might be required because of changes in the plume due to age of the landfill, quantity of precipitation and physical changes in the site, such as compaction or excavation.

In some instances site limitations may require that the extraction and injection wells are placed so close together that the radii of influence overlap. It may be desirable in these situations to place an impermeable barrier between the extraction and injection wells. The impermeable barrier must be placed to the depth of the first impermeable layer to avoid mixing of contaminated and noncontaminated water.

A system of extraction/injection wells is currently being used in Palo Alto, California to prevent salt water intrusion. The system designed for Palo Alto uses a series of 9 well pairs with a total pumping capacity of 2.0 MGD. This corresponds to an average pumping rate of 150 gpm. Pumping is conducted in an aquifer which is 45 feet deep with a transmissivity of 8700 gpd/ft and a coefficient of storativity equal to 3.6×10^{-5}. Optimum spacing between well pairs was determined to be 1000 feet.

Extraction wells alone can be used to collect leachate plumes. There are both advantages and disadvantages to this system as compared to the extraction/injection system. The withdrawal system does not incur the added pumping and maintenance costs for an injection system, but also does not have the advantage of replenishing the groundwater supply. Use of an extraction system alone would be best suited to sites where low rates of pumping are required to where the aquifer water supply is not needed as a drinking water source.

The design of an extraction system is considerably less complicated than the previously mentioned extraction/injection well systems, since the effects of the cone of impression from the injection wells need not be considered in determining the radius of influence needed to contain a plume. However, effective use of this system will still depend on the accurate and frequent monitoring of the plume and on a flexible design which can be adjusted as the plume changes.

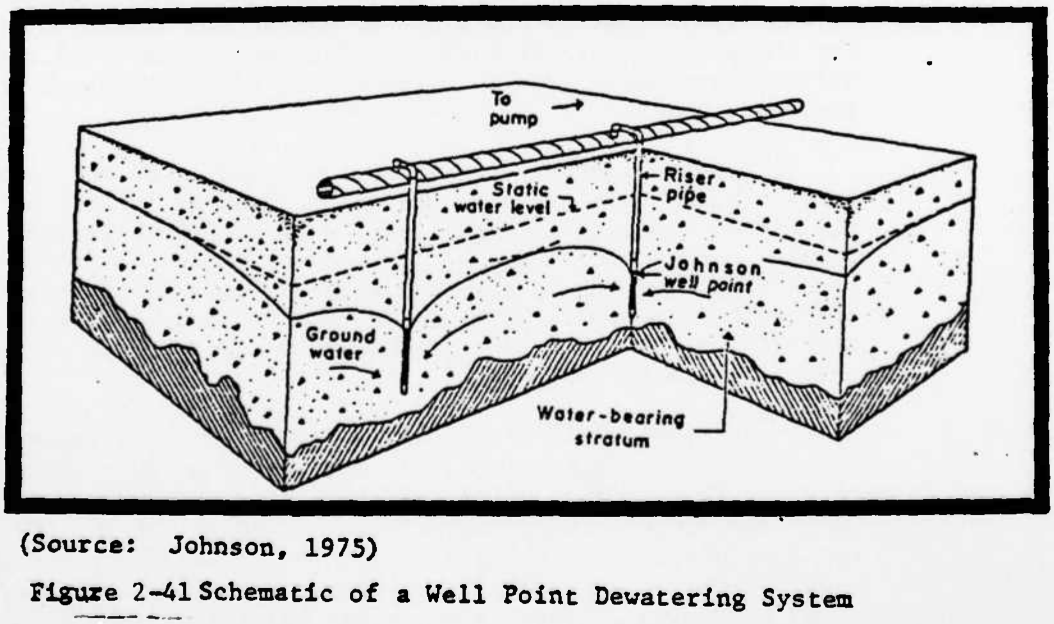
If groundwater recharge is necessary, a less costly alternative to the use of injection wells is the use of seepage or recharge basins. Since seepage basins require a high degree of maintenance to insure that porosity is not reduced, they would not be practical where several basins are required for recharge of large volumes of water or where adequate maintenance staff is not available.

The dimensions of a recharge basin vary considerably. The basin should be designed to include an emergency overflow and a sediment trap for runoff from rainwater. The side walls of the basin should be pervious, since considerable recharge can occur through the walls (Tourbier, 1974).

Well Point Systems

Well point systems are composed of a series of wells, usually connected by header pipes to a suction centrifugal pump. They may be used for both water table lowering and leachate plume containment.

As illustrated in Figure 2-41, the system consists of a group of closely spaced wells usually connected by a header pipe and pumped by suction centrifugal pumps, submersible pumps, or jet ejector



(Source: Johnson, 1975)

Figure 2-41 Schematic of a Well Point Dewatering System

pumps, depending on the depth of pumping and the volume to be dewatered. A pump may be connected to one well point or a central pump may be used for the entire well point system depending upon the depth, volume and permeability.

As Figure 2-41 shows, the header is connected to a swing fitting that contains a valve controlling water withdrawal from each individual well point.

Lowering the groundwater level over the desired site involves creating a composite cone of depression by pumping from the well point system. The individual cones of depression must be close enough together so that they overlap and thus pull the water table down several feet at intermediate points between pairs of wells (Johnson, 1975). An illustration of this overlapping is provided in Figure 2-42 below.

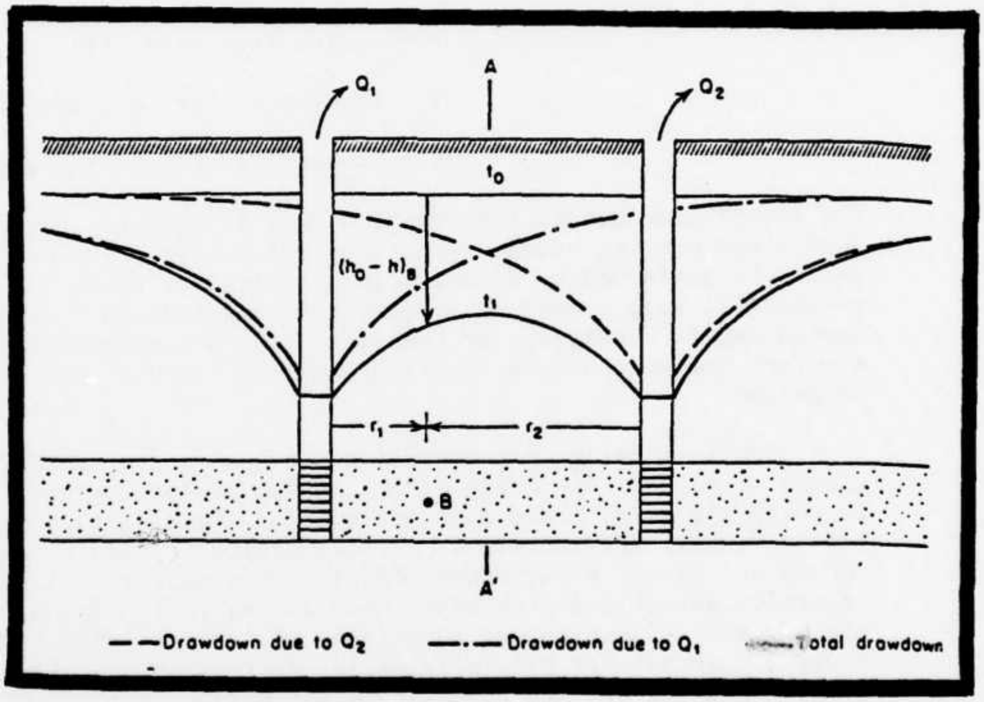


Figure 2-42 Drawdown in Potentiometric Surface of a Confined Aquifer Being Pumped by Two Wells

(Source: Freeze, 1979)

The amount of drawdown provided is calculated using the Theis equation, which uses data on the aquifer's storativity and transmissivity.

The Theis equation, used to estimate drawdown, is expressed as follows:

$$ho - h = \frac{Q}{4 \pi T} W(u)$$

where: $ho - h$ = Drawdown (ft)

Q = Pumping rate (gal/m)

$W(u)$ = Well function; dimensionless

$$u = \frac{r^2 S}{4Tt}$$

r = Radius from well (ft)

T = Transmissivity (gal/day/ft)

S = Storativity (dimensionless)

The information needed for this equation is normally generated through short-term pumping tests. The tests and design of a well point system should be performed by a qualified hydrologist, since the design of a system will vary considerably depending on the depth to which dewatering is required, the transmissivity and storativity of the aquifer, the size of the landfill, and the depth of the water-bearing formation.

Important design considerations include depth, spacing, and sizing of pipes. The depth of the system is determined by the depth to which the water table must be lowered. Spacing is dependent on the transmissivity and storativity of the aquifer, which determines the amount and radius of drawdown effects. Sizing for well points is generally determined from experience and verified in the field. For silt or other fine-grained materials, well points with a diameter of about 1.5 inches are generally satisfactory when centrifugal suction pumps are used, but the necessary diameter can increase up to 6 inches depending upon the permeability of the soil. One-inch diameter riser pipes are suitable for small-diameter well points and should be increased to 2.0 to 2.5 inches for well points with a diameter of 3.5 inches. Headers should be about 6 inches in diameter.

Well point systems can also be used for plume containment. They are more flexible than single extraction wells and can be readily adjusted to account for changes in the plume. The design criteria for plume containment are the similiar to those for dewatering. The

number of well points needed to contain the plume is determined by applying the equations for composite drawdown radii by the wells in the system.

An example of an effective system for plume containment is currently operating at the Rocky Mountain Arsenal, and is undergoing design injection wells to the other side of an impermeable barrier. The completed system will handle a flow of 443 gpm and will extend for 5200 feet. The system will consist of about 33 extraction wells most of which are 8 inches in diameter, and approximately 40 injection wells with a diameter of 16 to 18 inches. The extraction and injection systems are separated by an impermeable barrier.

2.4.4 Leachate Collection Facilities

An integral part of the containment approach to leachate control should involve the use of collection and extraction facilities to enable removal of leachate from the landfill.

Ideally, collection systems incorporated into the design of a lined landfill can relieve hydraulic pressure on the liner. To facilitate leachate removal, liner materials should be sloped to drain to one or more points (preferrably a grade of 1 percent or greater). Leachate is usually removed at a perimeter, internal sump coordinated with a perimeter base trench consisting of perforated drain pipe and gravel backfill. Leachate flows laterally to the drain and then into a gathering sump where it can be extracted by pumping. Leachate can then be routed to a treatment system for chemical, physical, and biological treatment before it is discharged to surface streams. Figure 2-43 illustrates a leachate collection drain system.

2.4.5 Leachate Treatment Options

Collected landfill leachate should be disposed to the land or surface water in an environmentally sound manner. Such treatment is mandated in the Clean Water Act of 1977 (33 U.S.C. 1251) which stipulates that a permit is required for the discharge of collected leachate to surface water.

The technology for leachate treatment is evolving rapidly. In general, the philosophy is to reduce the contaminants to the extent that the treated liquid can be discharged to the environment while still maintaining environmental security in a manner satisfactory to the local regulatory bodies. Various methods of leachate treatment and discharge are available to the designer-operator of landfills, including: direct discharge to sewer or liquid waste treatment with eventual discharge to the environment; recirculation in the landfill to accelerate biostabilization; spray irrigation or land application; injection of leachate into the fill; and evaporation ponds.

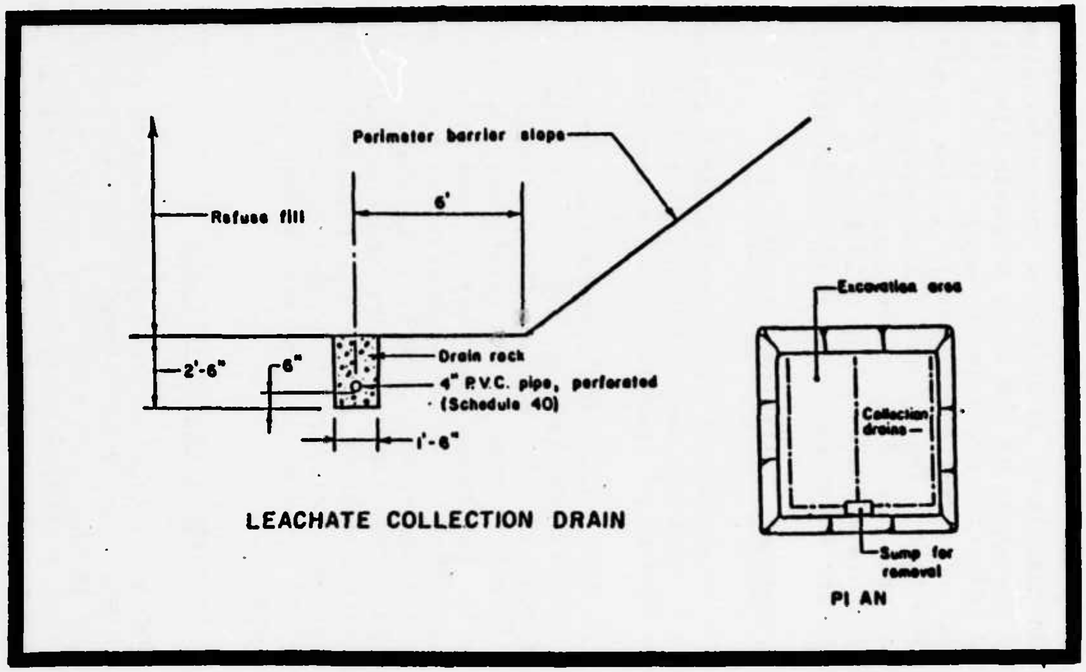


Figure 2-43 Leachate Collection Drain System

2.4.6 On-Site Treatment

If sanitary sewers or waste treatment facilities do not lie in close proximity to the landfill, on-site treatment may be required. Until now, on-site treatment has seen limited use. On-site treatment typically follows a pattern of providing a treatment pond or ponds with aerators. The purpose of the aerators is to add oxygen to the leachate in an attempt to remove the organic loadings. If the leachate strength is high (relatively high concentration of BOD/COD and presence of heavy metals), an initial pond or section of the treatment should allow a greater than 90% BOD reduction for hydraulic detention time of approximately 10 days at a temperature range of 23 to 33°C. Relatively little sludge is developed in this process. This stage is typically followed by an aerobic pond with a retention interval of about 10 days where up to 90% of the remaining organics can be removed and the effluent BOD can be controlled within the range of 25 mg/l (a control level deemed acceptable by many regulatory agencies in the United States). If the organic loading is found to be excessive, additional aerators can be added to the system.

Combined Anaerobic/Aerobic Treatment

The potential coupling of anaerobic and aerobic treatment offers and effective and inexpensive means to reduce pollution characteristics of landfill leachate. If the two systems are combined in one pond, the effective area of each system can be controlled by means of floating baffles to separate the two systems.

Chemical Treatment

Modest to large doses of chlorine can reduce COD as much as 25 to 50%. This treatment has the additional benefit of removing ion and coloring with minimal sludge production. If additional ingredients must be removed from the leachate before discharge is permitted, then certain filtration or additional chemical treatment must be provided, depending upon the discharge requirements.

2.4.7 Discharging Treated Leachate

Once the leachate has been collected, whether internally within the landfill or in an impoundment pond where it has received some initial treatment, the leachate can be discharged by spray irrigation on top of the landfill or to permitted adjacent areas for land spreading. The rate of application should be controlled so as to allow all the leachate to be absorbed within the application area.

2.4.8 Leachate Treatability

Table 2-3 summarizes the general effectiveness of various wastewater treatment techniques to remove chemical oxygen demand (COD), a

TABLE 2-3

LEACHATE TREATABILITY[1]

Leachate Quality		COD Removal Efficiency[2]						
Age	COD, (mg/l)	Biological	Chemical Precipitation	Chemical Oxidation	Ozonation	Reverse Osmosis	Activated Carbon	Ion Exchange
Fresh (5 year)	10,000	G	P	P	P	F	P	P
Medium (5 yr.-10 yr.)	500-10,000	F	F	F	F	G	F	F
Old (10 year)	500	P	P	F	F	G	G	F

1. Adapted from Chain, E.S.K. & F.B. DeWalle. "Sanitary Landfill Leachates and Their Treatment." Proceeding ASCE, Journal of the Environmental Engineering Division 102, EE2, 411-31. 1976.

2. Chemical Oxygen Demand Removal: G = Good, F = Fair, P = Poor.

prime measure of pollution for landfill leachate. Figure 4-44 shows a schematic of an on-site leachate treatment system.

2.4.9 Leachate Recirculation

A relatively new concept in leachate treatment is that of recirculation of leachate through the landfill to accelerate biostabilization. Recirculation essentially uses the landfill volume as an uncontrolled anaerobic digester for effective treatment of its own leachate. The recirculation of leachate increases the rate of biological stabilization of the organic fraction of the refuse, as evidenced by significant reductions in BOD and COD.

Effectiveness of Recirculation

The effectiveness of leachate recirculation in mitigating leachate pollution capacity will vary according to the leachate constituents. The components can be divided into three categories according to whether they might be effected to: degrade to non-toxic end products or change toward levels found in unpolluted waters; be relatively immobilized within the refuse mass by precipitation, absorption, chelation, or other mechanisms; or be unaffected and, therefore, available for continued leaching, irrespective of the extent of refuse decomposition or changes in the biological/physical-chemical conditions within the cell.

Impact on Leachate Components

In general, mineral components in varying forms are conserved and unaffected by bacterial action, while organic compounds and chemical species such as sulfate (SO_4) are transformed to end products such as methane (CH_4), carbon dioxide (CO_2), water (H_2O), and hydrogen sulfide (H_2S) on an inverse basis by leachate pH. Stabilization of the refuse usually results in elevation of the leachate pH, approaching neutrality, which tends to decrease the solubilization of many metallic ions, the transition elements zinc, cadmium, mercury, and lead being the most highly influenced. The halogens, alkali metals, and alkaline earths largely remain available for leaching under a wide range of conditions. These last may present the most likely compound to be leached from even a completely stabilized fill.

Recirculation of leachate is a highly effective method for achieving decreased organic loading as evidenced by a high (98+) percent removal of BOD, COD, and volatile acids (VA). BOD and COD of stabilized leachate are approximately equivalent to moderate strength municipal waste water. Recirculation can also be reasonably effective in reducing the total dissolved solids and total Kjeldahl nitrogen content, although these parameters will still be approximately an order of magnitude above that of municipal waste water. Researchers have found that artificial control of leachate pH near neutral values resulted in further acceleration of the stabilization of these

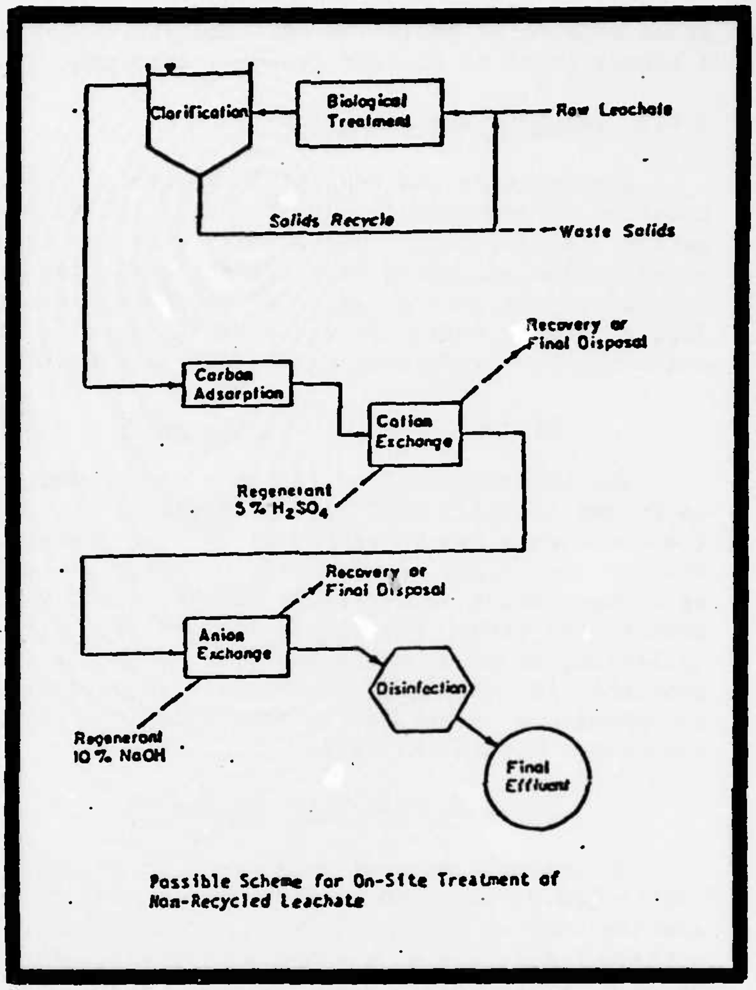


Figure 2-44 On-Site Treatment of Non-Recycled Leachate

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ASSESSMENT OF ALTERNATIVES FOR UPGRADING NAVY SOLID WASTE DISPO--ETC(U)

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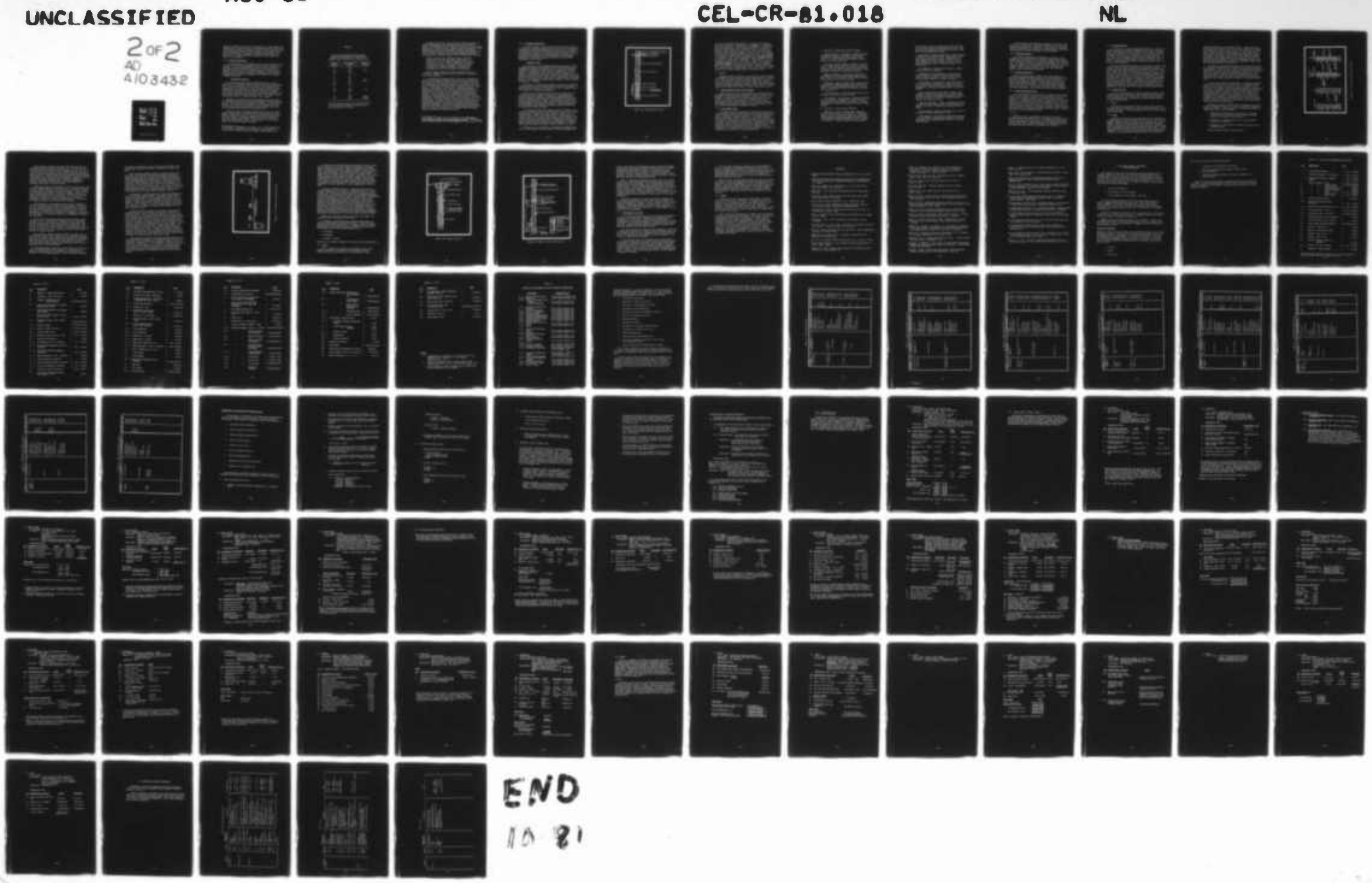

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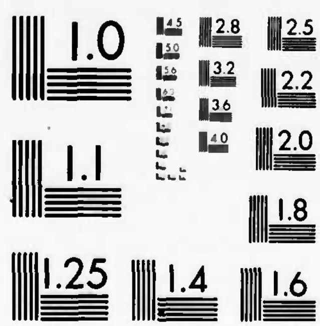

MICROCOPY RESOLUTION TEST CHART
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parameters beyond that provided by recycling alone. These observations indicate that the leachate from a recirculated landfill is likely to be significantly decreased in strength relative to unrecirculated leachate but for parameters other than organic loading, to be stronger than municipal waste water. Additional treatment efforts may need to be taken, then, to further attenuate the leachate from a recycled fill before it is discharged.

2.4.10 Leachate Attenuation

At some landfills, it is possible to rely on the attenuation capabilities of the natural hydrogeologic system to abate the impact of leachate. An exact characterization of the subsurface conditions at the landfill from the natural ground surface to the bottom of the uppermost saturated zone, and a reliable estimate of the anticipated leachate quality and rate of generation (EPA Water Balance Method is recommended) are required to determine if attenuation is a feasible treatment alternative.

Attenuation Processes

As leachate percolates through fine-grained soil, it reacts mechanically and chemically with the subsurface soil-water environment. One of the most important of these reactions is that involving ion fixation with the clay minerals of the soil system. Negative charges concentrated on the surface of the clay particles attract cations (positive ionic species) from the leachate. The total cations that can be held on any given soil type can be determined by laboratory test and is termed the cation exchange capacity (CEC). The higher the CEC, the better the ability to affix the cation in the leachate.

Although it is possible to give rough estimates of the potential for leachate attentuation through cation exchange, predicting which ions will be retained and which will continue to migrate is a very complex problem. CEC is only an aid in making relative comparison and does not give the actual milli-equivalents of a particular pollutant that will be removed from solution by a given mass of soil.

Studies by Griffin, Cartwright, Shimp, et al.*, rank the various chemical constituents in a municipal leachate according to relative mobility through laboratory soil columns of various clay-sand compositions (see Table 2-4). Results obtained from chemical analysis of sectioned columns revealed large accumulations of all four metals -- lead, zinc, cadmium and mercury -- in the surface 2 to 4 cm of each column, even those with high sand content.

*R.A. Griffin, K. Cartwright, N.F. Shimp, et. al., 1976, "Attenuation of Pollutants in Municipal Landfill Leachate by Clay Minerals," Illinois State Geology Survey, Environmental Geology Notes No. 78.

TABLE 2-4

RANKING OF CHEMICAL CONSTITUENTS IN MUNICIPAL LEACHATE
ACCORDING TO RELATIVE ATTENUATION IN CLAY MINERAL COLUMNS
(Adapted from Table 4, Griffin, Cartwright, Shimp, et al., 1976)

Chemical Constituent	Mean Attenuation Number*	Qualitiative Grouping
Pb	99.8	
Zn	97.2	High
Cd	97.0	
Hg	96.8	
Fe	58.4	
Si	54.7	
K	38.2	Moderate
NH_4	37.1	
Mg	29.3	
COD	21.3	
Na	15.4	Low
Cl	10.7	
B	-11.8	
Mn	-95.4	Negative (elution)
Ca	-656.7	

*Mean Attenuation Number - Quantification of individual ion attenuation; percent removal after passage of a standardized volume of leachate through laboratory soil columns.

Mechanical filtration by soil is also an effective process in leachate attenuation. Most suspended matter and a substantial number of microorganisms will be removed from leachate by its passage through only a few feet of soil. Hughes, Landon, and Farvolden (1971)[†] presented the results of hydrogeologic studies of five landfill sites developed on glacial till with clay minerals predominantly from the Illite group. They gave the following estimates of leachate attenuation to be expected in glacial tills of Northeastern Illinois:

> Silty and clayey tills, unfractured shales, and clays should reduce the total dissolved solids content of leachate by one to two orders of magnitude in traveling a distance of 5 feet. Sands and silts will reduce the total dissolved solids in leachate by about one order of magnitude in traveling 500 feet, and gravels and fractured rocks will be considerably less efficient.

Microbiological action in the soil may further aid in the breakdown of organic compounds and the oxidation of inorganics to less soluble compounds.

In designing and operating landfill sites, it is possible to enhance the attenuation properties of the site soils by maximizing the flow path of leachate through surficial soils beneath the site and eliminating direct channels through the soil layer. Soils that do not attenuate leachate naturally may be altered physically, chemically, or biologically to facilitate the attenuation process. For example, increasing soil pH is likely to increase attenuation of heavy metals. Attenuation can be increased by reducing flow rate, eliminating cracks in the soil and exposing fresh soil particle surfaces. These techniques may be implemented by disturbing and compacting soil in preparing the land for waste disposal. Specific approaches to enhancing attenuation are, of course, a function of the hydrogeology of each site and must therefore be developed on a case-by-case basis. The degree of reliance on natural site attenuation conditions depends upon the degree of protection required for the underlying groundwater. Where natural hydrogeologic conditions are sufficient to mitigate the impact of leachate upon underlying groundwater, no natural or synthetic liner is required under the refuse (beyond the naturally occuring soil layers).

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†G.M. Hughs, R.A. Landon, and R.N. Farvolden, 1971, Hydrogeology of Solid Waste Disposal Sites in Northeastern Illinois. U.S. Environmental Protection Agency, Solid Waste Management Service, Report SW-12d.

2.4.11 Groundwater Monitoring

Solid waste landfill disposal facilities should be monitored to determine when contingency remedial action plans should be implemented. A groundwater monitoring system should be installed for the purpose of detecting the impact of all landfill disposal facilities which have the potential for discharge to an underground drinking water source. Publication EPA/530/SW-611, entitled "Procedures for Groundwater Monitoring at Solid Waste Disposal Facilities," provides helpful information on this subject.

Monitoring Wells

The objective of the groundwater monitoring system is to obtain representative samples of groundwater and to detect contamination in underground drinking water sources beyond the appropriate boundary. Generally, the uppermost aquifers will be of monitoring concern as leachate is concentrated in the first groundwater contacted. At a minimum, the monitoring system should have one well hydraulically upgradient from the site and at least two wells downgradient. The static water levels reported for the wells should indicate the local hydraulic gradient. The downgradient wells should be located at the solid waste (or alternate) boundary.

Groundwater or leachate monitoring wells should not be installed through the bottom of the landfill proper, since such a procedure could result in creation of a conduit for the direct passage of landfill leachate into underlying groundwater.

Wells within the landfill refuse are but not through the fill bottom used to monitor leachate levels and for early warning of potential migration problems. Upgradient and downgradient wells should be located so that samples are obtained from the same horizon of water-bearing materials so that a valid comparison can be made. When downgradient wells are being evaluated, local variations in the hydraulic gradient (such as may be caused by a nearby pumping well or a groundwater mound beneath the facility) should be considered, as well as any vertical gradients.

In constructing wells, well casings should be a minimum of two inches in diameter, preferably four inches, to allow for both pumping and sampling. A typical well design is shown on Figure 4-45. A bentonite clay or cement seal plug should be in place around the casing, finished at the surface with a cement or earth mound sloped away from the well to prevent surface drainage down the casing. The top of the well should be covered with a locking cap and protected against vandalism and destruction by mobile equipment. In addition, wells should be labeled to indicate the well location and number.

Groundwater can be monitored for the maximum contaminant levels (MCL's) of the National Interim Primary Drinking Water Regulations,

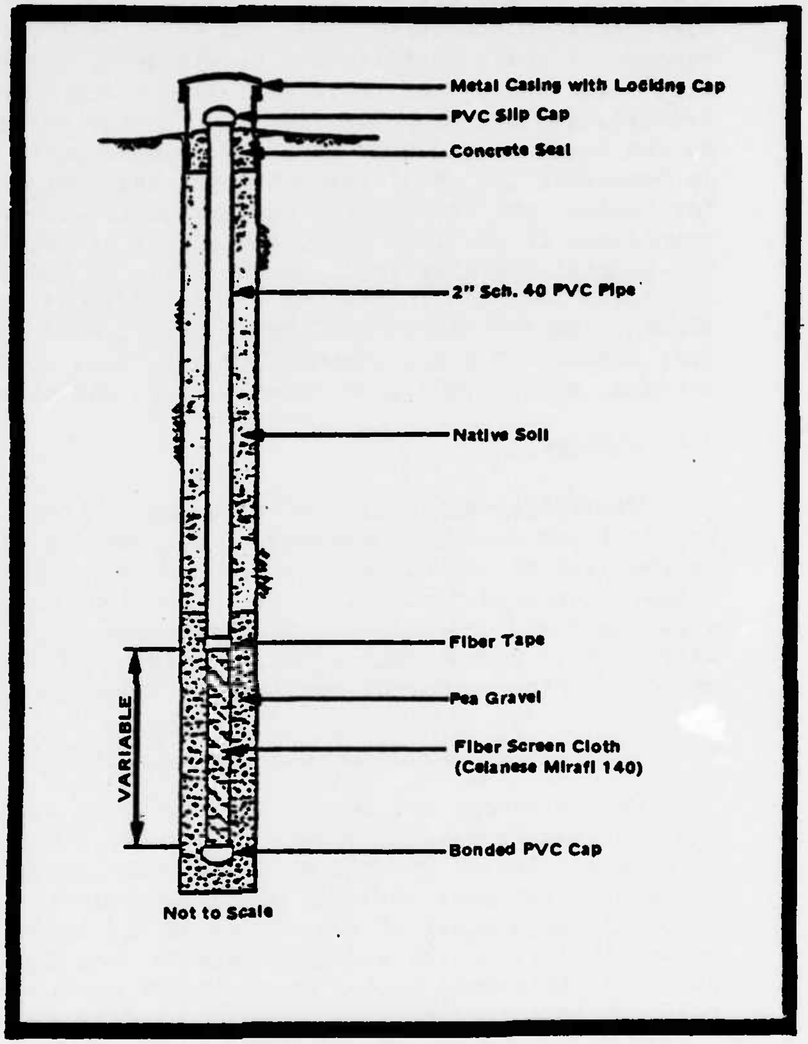

Figure 2-45 Monitoring Well Detail

or it can be monitored more generally for a variety of tracers or indicators of potential contamination. At minimum, it is suggested that four parameters -- total dissolved solids (TDS), chloride (Cl), electrical conductivity (EC), and nitrates (NO3) -- be monitored because of their mobility and persistance, their known association with solid waste, and their inclusion (except for EC) in the Federal Criteria and the proposed amendment to the Criteria. In an appendix to the Criteria (40 CFR, Part 257) appearing in the Federal Register on September 13, 1979, the EPA published maximum contaminent levels for logical and radioactive contaminants. These levels will not be reproduced in entirety here, since they are spelled out in detail in the Federal Register (Vol. 44, No. 179, p. 53464). The inorganic chemicals included in the EPA's list (maximum acceptable levels are shown in parenthese in milligrams per liter): arsenic (0.05); barium (1); cadmium (0.010); chromium (0.05); lead (0.05); mercury (0.002); nitrate, as N (0.002); selenium (0.01); and silver (0.05).

2.5 DISEASE

Mismanaged sanitary landfills can create a major health problem by providing food and harborage for common disease vectors. Included in the list of common vectors are rats and other rodents, domestic flies, arthropods other than flies (such as mosquitos), birds, and stray cats and dogs. Oppossums, raccoons, skunks, and bears are also attracted to garbage dumps and, by virtue of their ability to transmit rabies, create potential problems for humans living near the site.

2.5.1 Sewage Sludge and Septic Tank Pumpings

Sewage sludge and septic tank pumpings must undergo either an EPA approved Process to Reduce Pathogens or Process to Further Reduce Pathogens. The acceptable practices are listed in section 2.1.5, Disease. Treatment with one of these processes should take place prior to the arrival of the sludge at the landfill and is the responsibility of the sludge generator, not the landfill operator. The landfill should accept no sludge or septic tank pumpings which have not been treated with an appropriate process.

2.5.2 Controlling Vectors

The single most effective method of controlling these vectors is a conscientious program to minimize harborage and food availability, thereby creating an inhospitable habitat. The regular application of daily, intermediate and final earth cover to the wastes should be sufficient for this purpose. Studies have shown that a daily cover of 6 inches of compacted soil will seal off the food supply and reduce harborage. Such an approach discourages the propagation of rats and flies, which tend to be the two most prolific landfill vectors. Other potential sources for harborage which can be minimized are the accumulation of salvage materials, landclearing debris, and rubble for subsequent use as road base or erosion protection.

A. Processes to Significantly Reduce Pathogens

Aerobic digestion: The process is conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15°C to 40 days at 20°C, with a volatile solids reduction of at least 38 percent.

Air Drying: Liquid sludge is allowed to drain and/or dry on under-drained sand beds, or paved or unpaved basins in which the sludge is at a depth of nine inches. A minimum of three months is needed, two months of which temperatures average on a daily basis above 0°C.

Anaerobic digestion: The process is conducted in the absence of air at residence times ranging from 60 days at 20°C to 15 days at 35° to 55°C, with a volatile solids reduction of at least 38 percent.

Composting: Using the within-vessel, static aerated pile or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40°C for 5 days. For four hours during this period the temperature exceeds 55°C.

Lime Stabilization: Sufficient lime is added to produce a pH of 12 after 2 hours of contact.

Other Methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

B. Processes to Further Reduce Pathogens

Composting: Using the within-vessel composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the static aerated pile composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the windrow composting method,

the solid waste attains a temperature of 55°C or greater for at least 15 days during the composting period. Also, during the high temperature period, there will be a minimum of five turnings of the windrow.

Heat Drying: Dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10 percent or lower. Sludge particles reach temperatures well in excess of 80°C, or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the dryer is in excess of 80°C.

Heat Treatment: Liquid sludge is heated to temperatures of 180°C for 30 minutes.

Thermophilic Aerobic Digestion: Liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55-60°C, with a volatile solids reduction of at least 38 percent.

Other Methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent' equivalent to the reduction achieved by any of the above methods.

Any of the processes listed below, if added to the processes described in Section A above, further reduce pathogens. Because the processes listed below, on their own, do not reduce the attraction of disease vectors, they are only add-on in nature.

Beta ray irradiation: Sludge is irradiated with beta rays from certain isotopes, such as Cobalt and Cesium, at dosages of at least 1.0 megarad at room temperature (ca. 20°C).

Pasteurization: Sludge is maintained for at least 30 minutes at a minimum temperature of 70°C.

Other Methods: Other methods or operating conditions may be acceptable if pathogens are reduced to an extent equivalent to the reduction achieved by any of the above add-on methods.

Another method to discourage the development of a vector population is waste pretreatment. Shredding, milling and baling are techniques which minimize the attraction of certain vectors. Biological reduction (pre-digestion of organics) or wastes prior to landfilling, when appropriate, may also discourage vector development.

2.5.3 Controlling Rodents

Where rodent populations are indigenous to the area, control programs may be necessary around or near the site perimeter. Some rodenticides are effective and, when applied properly, environmentally safe. For example, Warfarin is a very common compound used to poison rats. In cases where rats become immune to this chemical, a new toxin, brandnamed "Talon", has been approved for use on these resistant rodents. Landfill operators should check with local regulatory agencies before using any such chemicals.

2.5.4 Controlling Mosquitos

Mosquito control is also important, since these insects are capable of transmitting malaria, yellow fever and encephalitis. The best defense against the establishment of a mosquito population is proper site drainage to eliminate stagnant water pools, which are prime mosquito breeding grounds. In cases where ponding or water cannot be avoided, the introduction of fish which feed on mosquito larva may be effective. State Fish and Wildlife Agency biologists can provide information on which fish are suitable for this purpose.

2.5.5 Controlling Health Hazards

Those health hazards which do exist at a disposal site generally pertain to site workers, in particular the equipment operators. Such hazards include possible exposure to pathogenic wastes or toxic, explosive, or flammable materials which, although barred from sanitary landfills, may nevertheless occasionally be brought to the site mixed with ordinary municipal refuse. Proper disposal practices, such as immediate burial of hospital wastes in the landfill, availability of first aid supplies, provision of hygienic facilities, and the training and experience of the disposal operators' employees, greatly minimize exposure to the above-described hazards.

2.6 AIR

Landfills at which a ban against open burning is strictly enforced should easily comply with this criterion, providing no other source of on-site air pollution (e.g., and incinerator) exists which could violate applicable requirements of the appropriate State Implementation Plan (SIP). Careful enforcement of a no-burning policy is the single most effective means of meeting this criterion.

2.6.1 Controlling Fires

In concert with a rigid ban against open burning, the second most effective program is one aimed at minimizing the risk of accidental fires. Since organic matter left exposed to free oxygen can achieve spontaneous combustion, it is imperative that such wastes be covered on a daily basis to limit the quantity of free oxygen available. Soil cover not only minimizes the likelihood of combustion, but will isolate any fires which may develop to the cell in which it was started. Compaction, which decreases available air space within the fill, is also recommended.

The third most effective method for controlling air pollution from landfill fires is simple, common-sense site operation practices. All equipment operators should keep fire extinguishers on their machines at all times, since they may be able to put out a small fire. If the fire is too large, waste in the burning area should be spread out so that water can be applied. This can be an extremely hazardous chore, and water should be sprayed on those parts of the machine that come in contact with the hot wastes to protect the operator and equipment. Obviously, if a hauler arrives at a landfill with a burning or hot load, he should be directed to a separate area of the landfill, away from the working face, where the fire can be extinguished prior to landfilling. Moreover, each landfill should maintain a clear fire-fighting plan with which all site personnel are thoroughly familiar.

2.6.2 Controlling Dust

At active disposal sites, some dust is usually generated during excavation and covery operations. This problem can be controlled by watering access roads and working areas. Blowing paper and debris can be controlled by use of portable litter fences placed adjacent to active disposal areas.

2.7 SAFETY

This criterion is designed to ensure that the public safety is not threatened by landfill gases, fires, uncontrolled access, or bird hazards to aircraft. Control technologies for each of these conditions are discussed below.

2.7.1 Gases

The Federal criterion for gases requires that the concentration of explosive gases in facility structures and in soil at the facility boundary remain less than 25 percent of the lower explosive limit for methane. Combustible gases generated within landfills can migrate through the cover soil, base and side walls, eventually finding their way to the surface and thus posing a potential safety threat. In many cases, above-ground landfills and those below-ground landfills in an impermeable soil or rock environment present no lateral gas migration concerns. In these situations, the main concern is protection of

people and structures at the landfill surface. On the other hand, at landfills with permeable side walls or base, especially if coupled with an impervious cap, the need for vents or barriers may be imperative for control of lateral gas movement. In still another case, where utility pipelines or similar underground conveyances penetrate the landfill's side walls, some kind of lateral control system may be required. This latter condition can be one of the most prolific causes of lateral migration; in several well-documented cases, landfill-generated gases have been detected in underground conduits over 1000 feet from the edge of the facility.

The first step in establishing the need for a gas control system is a thorough investigation of the landfill's gas production/migration characteristics. This involves a review of pertinent design and construction data (depth, soil characteristics, refuse type and location, cover soil, liners and method of landfilling) followed by a field monitoring program. The field monitoring program may employ gas monitoring wells, shallow gas probes, and/or hand-held gas detectors employed on the landfill, along its perimeter or on adjacent properties.

The effects of climate on gas movement in a landfill environment must also be considered in the design phase. For example, certain climatic effects such as rain, ice or frost can render any type of cover soil less permeable, thereby encouraging the lateral migration of the gas. In addition to decreasing soil permeability and modifying gas migration patterns, rainwater or snow melt may infiltrate the refuse, resulting in an increase or decrease in the rate of waste decomposition and, therefore, gas production. This combination of decreased cover permeability and enhanced production may result in increased lateral migration during wet seasons. Therefore, landfill planners would be well advised to consider the site's climatological conditions during the design phase.

Methods for control of landfill gas are classified as active or passive, depending on whether or not gas is forceably withdrawn from protective features. Specific methods of controlling gas migration include one or more of the following:

- Construction of impervious liner materials to block subsurface gas flow to adjacent lands or protect buildings located on the landfill itself (passive)

- Utilization of granular materials for collection and/or venting of gas (passive)

- Atmospheric or pumped wells for removal and venting of gas (passive/active).

Figure 2-46 shows several of these systems.

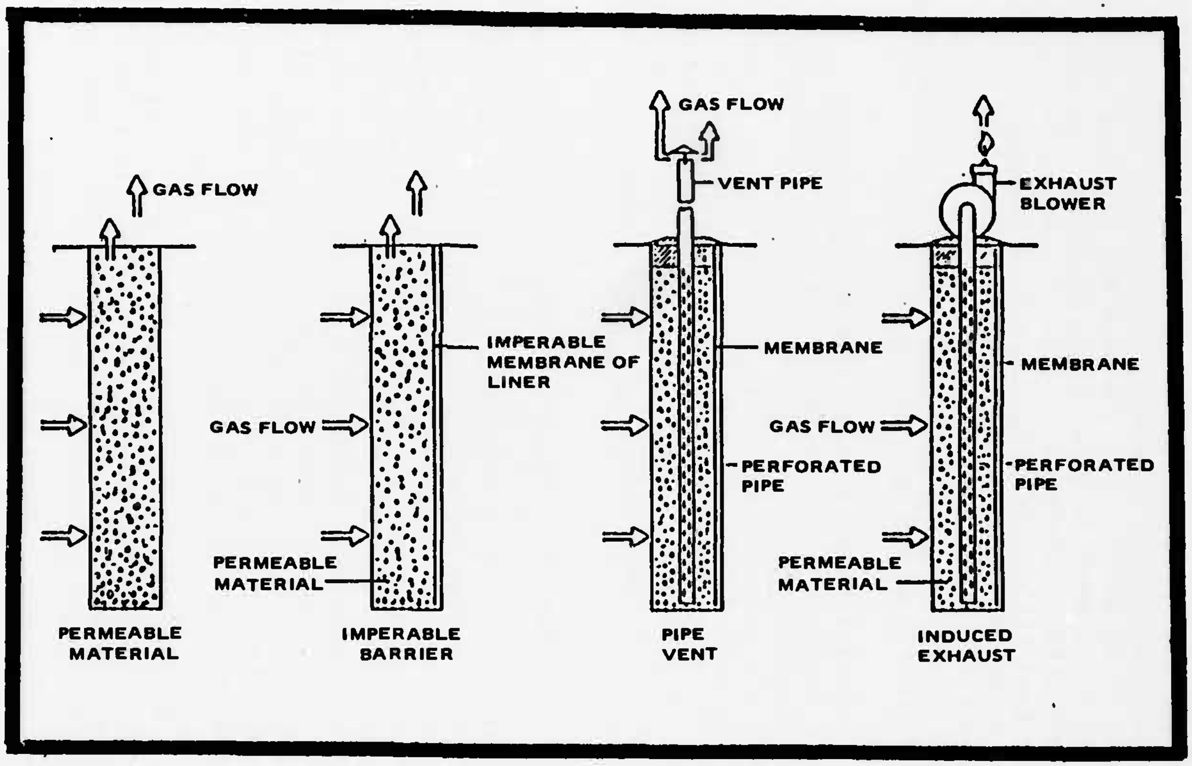

Figure 2-46 Schematic of Gas Control Systems

Passive control systems are typically used where the depth to a naturally occuring gas barrier is shallow, i.e., less than 20 feet. Natural gas barriers include shallow groundwater or thick clay layers. In construction of new disposal areas, gas barriers can be placed on perimeter and bottom excavation slopes, much as described under groundwater protection. Where landfills have been placed in deep excavations and/or there are no shallow natural gas barriers, an active gas control system must be used to draw gas away from landfill perimeters. A series of active gas withdrawal wells is currently operating in a landfill in southern California where wastes were placed in an abandoned gravel quarry over 100 feet deep.

Impervious liners for containing gas flow are of three basic types: synthetic, admixed materials, and natural soil. Liners are frequently the most important feature of a gas control system. Synthetic liners are manufactured using rubber or plastic compounding. Since the integrity of impermeable membranes is critical, methods of sealing and installing the membrane are very important. Some liners are factory sealed, while others are laid out in strips and sealed on-site. Attachment of membranes to dissimilar materials (e.g., utility lines and foundation support piles) must also be considered.

The possibility of using admixed materials such as asphaltic concrete for lining purposes should not be overlooked. Although they are not as popular for gas control as synthetic membranes, asphalts have the primary advantages of universal availability, low cost, and the ability to maintain their integrity under structures. The disadvantages are relatively high permeability (as compared to synthetics) and the tendency to crack under conditions of differential settlement and weathering.

Natural soil barriers, most notably clay, may provide a highly efficient barrier to gas migration provided the soil is kept nearly saturated. Dry soils are relatively ineffective, since cracks may develop opening the pore space, allowing gas to pass through. Native clay soils, either left in their natural state or modified by compaction, can provide an effective barrier. Alternate barrier materials such as bentonite may be used in cases where on-site soils are not sutiable for control purposes.

Liner materials, whether synthetic, admixed or natural soil, are best installed during landfill construction, as subsequent installations are often costly, less extensive than required, and occasionally impossible to perform. During construction, barriers can be placed to cover the base and sides of the fill and measures can be taken to cover them with an inner lining of protective material (e.g., sand or pea gravel) prior to refuse placement.

Of equal importance to the kind of liner selected is the type of collection/removal/venting system employed at a particular site. A number of technologies which are available for these purposes are described in the following paragraphs. Since the range of conditions

encountered at landfills across the country may vary widely, such technologies must often be modified or eliminated to match local needs.

Gravel trenches, perimeter rubble vent stacks, gravel-filled vent wells, and combinations thereof are examples of perimeter migration control systems. Venting systems may be either passive (relying on naturally occurring pressure of diffusion gradients) or active (inducing exhaust by using blowers or wind vents to create a vacuum pressure gradient), with selection being dependent on site conditions. Passive systems can be effective in controlling convective gas flow, but not diffusive flow. Since there are numerous instances where passive flow controls have been ineffective, the user should question the value of a passive perimeter control system; nevertheless, many have been constructed and are effective.

A combination of gravel-filled trench and barrier membrane can be a very effective passive system if the control trench depth is within the backhoe depth limit and an impermeable barrier exists within this depth limit. In this instance, the trench is due and a membrane is placed across the bottom and up the wall away from the landfill. Gravel is then used to backfill the trency; a vent pipe may or may not be included. This fairly common passive vent system is well suited to a landfill of shallow depth located in an area with a high water table.

Induced or active flow systems, particularly those employing suitably designed vertical wells, have proven very effective in migration control. From a practical standpoint, systems combining both migration control and gas recovery are finding increased favor. These systems usually incorporate perforated pipe in grouped vertical gravel filled wells similar to those used in gas recovery systems. The wells are spaced at regular intervals near the perimeter of the landfill, located either inside the limit of fill or outside it in the surrounding natural soils, depending on system requirements. The wells are connected by manifolds to a central exhaust pump which draws gas from the well field. The gas flow within the landfill is directed toward each of the wells, thereby effectively controlling migration. Alternatively, the collection pipe can also be placed in a gravel filled trench and then connected to a vacuum exhaust system to enhance the control ability of the trench system.

Gases collected by exhaust systems are generally disposed of by direct stacking, incineration, or by passage through various absorption media. Gases from passive vent systems are usually flared, as illustrated in Figure 2-47. In all instances, uncombusted gas must be vented at a location where it is not subject to careless ignition, i.e., generally in a protected enclosure or above normal reach. Malodors associated with uncombusted gas may dictate some form of odor control; ignition is the simplest and most effective malador control.

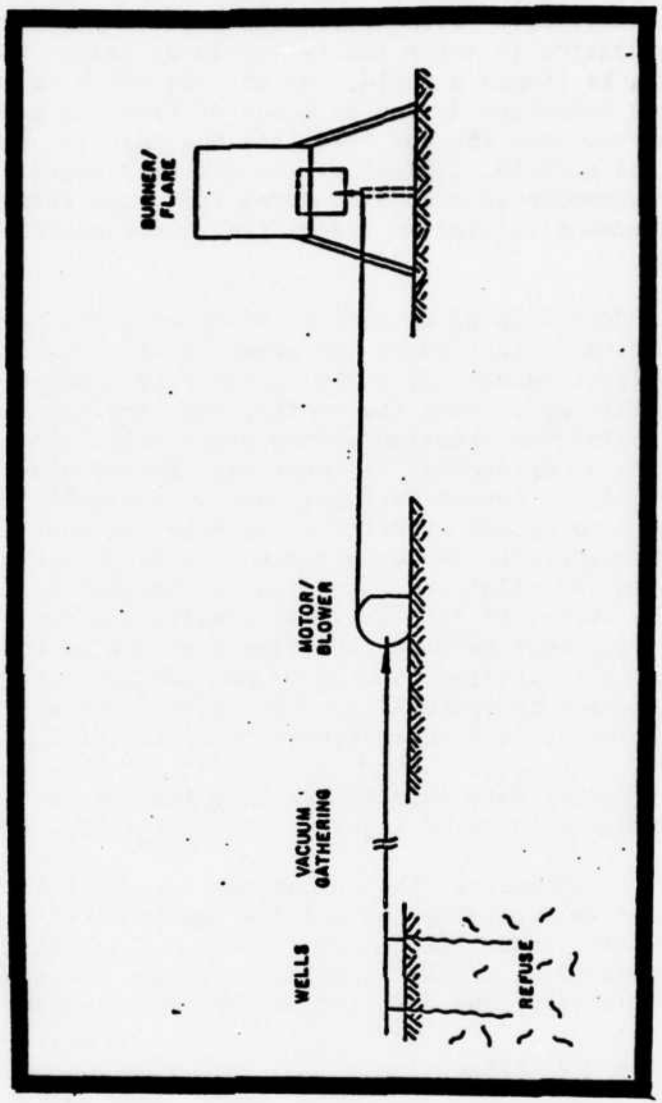

Figure 2-47 Conceptual Gas Control Facility

To ensure that the Federal criterion for gases is properly implemented, perimeter soil and all enclosed structures at solid waste facilities should be monitored to detect accumulations of explosive gases. The perimeter soil may be sampled by means of probes installed at the property boundary. The simplest method of monitoring gas composition in soils and refuse is by means of a bar-hole probe. The probe is simply a rigid, hollow tube which is attached to the inlet of a gas detection device by means of flexible tubing. The probe is inserted into the bar hole, and the hole is sealed around the probe at the surface, typically with rubber stopper, cloth, or native soil. A gas sample is then drawn from the probe through the gas detection instrument, giving an indication of the gas composition in the bar-hole.

Detection of methane by means of a bar-hole probe may give a positive indication of the presence of combustible gas, but a failure to detect methane does not necessarily indicate the absence of combustible gas. Most frequently, gas sampling is attempted immediately following the creation of the probe hole. The accumulation of migrating gas to a representative level may require minutes, hours, or days. In numerous investigations, shallow bar-hole probe surveys have failed to detect significant methane concentrations, and subsequent monitoring with deeper permanent probes has shown the gas to be present at relatively high levels. Another limitation of the bar-hole probe survey is the fact that results are not repeatable because a new hole must be made each time a survey is conducted. For these reasons, installation of permanent gas monitoring probes with periodic monitoring is preferable to bar-hole probe surveys when investigating the presence and characteristics of landfill gas in soils or refuse.

Figure 2-48 illustrates a typical gas probe, while Figure 2-49 presents details of a gas probe tip and top.

To summarize, the technology for controlling migrating gas is fairly well established and reasonably diverse. It has been proven effective under limited conditions. All systems require an extensive understanding of the landfill's design, construction and gas production history, and most technologies concentrate on:

- Collection
- Withdrawal
- Venting or flaring.

Monitoring is a necessary component of the gas control system selected.

2.7.2 Fires

Fires in landfills can result from the dumping of hot loads, sparks from vehicles, and spontaneous or deliberate ignition, although the latter is unlikely at a well-run landfill. Fires

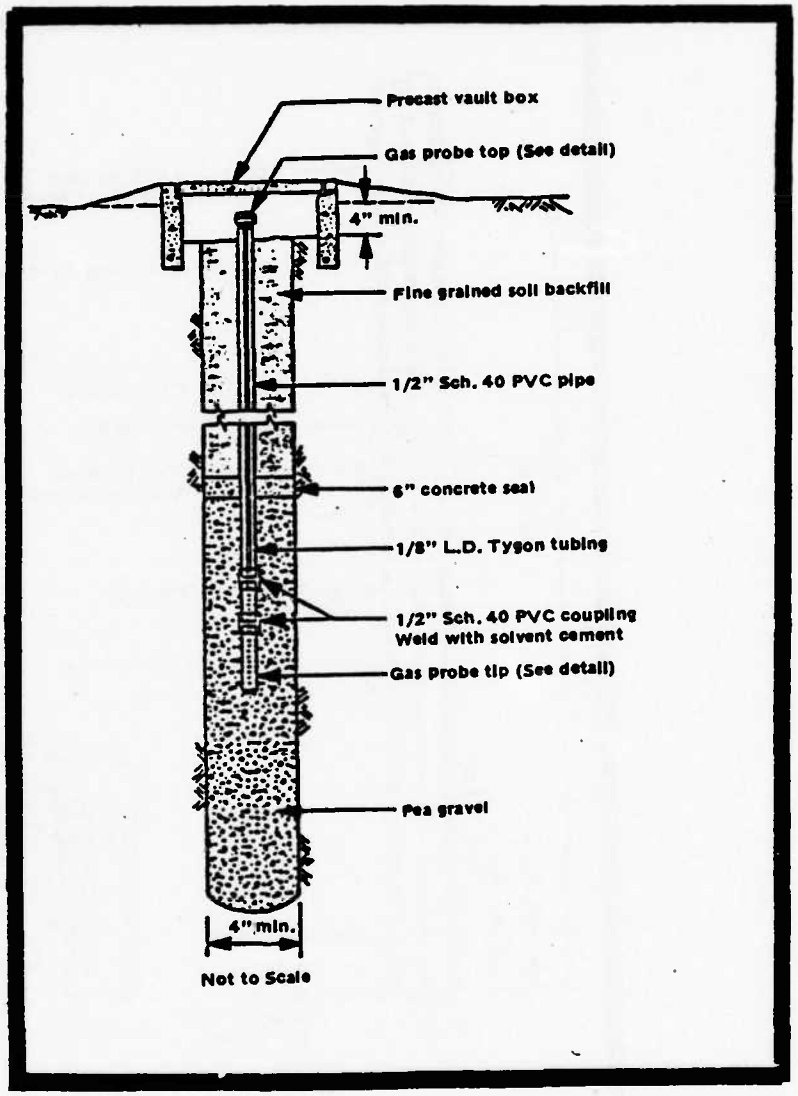

Figure 2-48 Typical Gas Probe

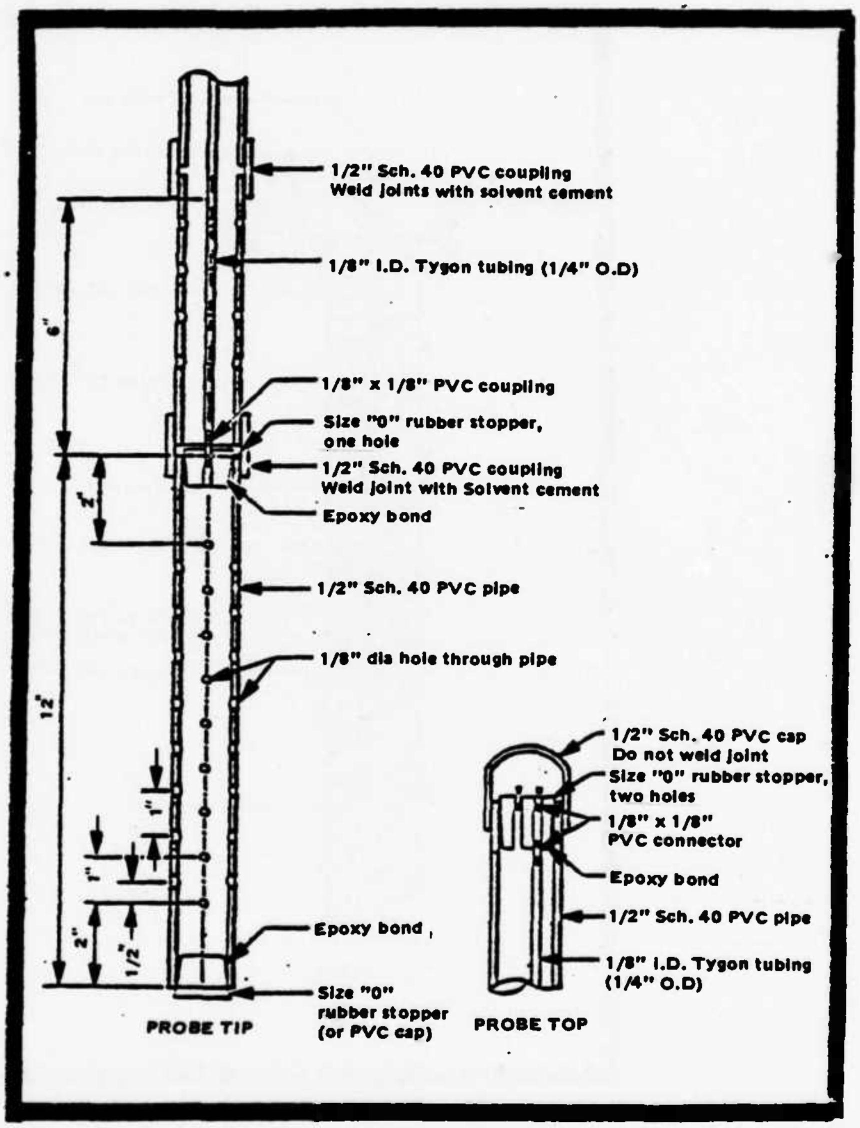

Figure 2-49 Detail - Gas Probe Tip and Top

caused by hot loads can be minimized by proper policing of incoming trucks; these loads should be depositied away from the working face and immediately extinguished by water or by covering with soil. Adequate daily soil cover is essential to smother any potential fire and to provide a natural barrier to a fire and prevent it from spreading. In fact, covering a fire with soil is often more effective than water application in extinguishing fires.

Fires at landfills are infrequent, and most occur in or on the working face. Those that break out in the fill close to the surface should be dug out and smothered. Deep fires should be smothered by placing moist soil on the surface and by constructing soil barriers around the fire. Where this smothering technique fails, the material must be excavated and smothered or quenched with water once it is brought to the surface. Water is usually not effective unless it can be applied directly to the burning material. As a precaution, the fire department should always be called to the site when a fire is being extinguished.

The specific quantity of on-site water and/or stockpiled soil that regulatory agencies will require varies widely throughout the country and depends on a number of factors, especially types of wastes received, climate, and proximity to populated areas. For water requirements, a 2000-gallon water truck with a hose attachment for spraying water on a fire will often suffice. Such equipment can also be used for dust suppression.

2.7.3 Bird Hazards to Aircraft

Of the several techniques in use for controlling bird hazards to aircraft, the foremost is the minimization of harborage and food availability at the landfill. Limiting food and harborage is accomplished by (1) locating landfills in areas less likely to attract birds and (2) by periodically applying cover material during landfill operation. Whenever possible, landfills should be located distant from the flight path of birds and/or aircraft.

Two other techniques are worthy of note, specifically "teleshot", a shotgun shell loaded with a secondary aerial detonation charge, and wire "cable canopy", thin wires suspended over the active fill area. The City of San Diego has had success with these two methods in the control of seagulls at two landfills.

In the teleshot method, site personnel first become familiar with the habits of the gulls and watch for the early morning "scouts" to approach the landfill. The scouts usually approach the landfill each morning in small flocks containing an odd number of seagulls (usually three to five). A shot is fired over the approaching flock and is followed by additional shots, as necessary, to discourage the group. A watchful eye is kept throughout the day, and the procedure is repeated as required.

The wire canopy involves the installation of a suspended wire system. Fine gauge, seven-strand stainless steel wires (485 lb. test) are suspended (at 150-200 lbs. of tension) over the active fill from pipe columns spaced at 40 foot intervals (horizontal dimension). Seagulls approach the wires and then veer off just above them. Some gulls land outside the wires, but refrain from walking beneath the wires toward the fill area.

While it appears that San Diego's methods have met with considerable success, it must be remembered that these techniques have not been used to control other species of birds or in other parts of the country. Also, the San Diego program has not been truly time-tested and must therefore be viewed with caution. To determine whether birds constitute a hazard to aircraft and which control techniques may be employed, a site-specific study must be completed for each landfill.

2.7.4 Access

Fencing is the most common means of controlling or limiting access to a disposal site. Permanent or portable woven and chain-link fencing, or a combination of both, are commonly used for these purposes. A gate should be provided at the site entrance which should be closed when the landfill is not open. Additional deterrents to access that may be helpful include earth berms, ditches, and such natural features as hills, slopes, water, or wooded areas to serve as visual screens.

This concludes the presentation of remedial action technologies available to the Naval landfill operator. For each of the Criteria of the Resource Conservation and Recovery Act, several remedial technologies exist to correct non-compliance. This chapter has presented the conventional technologies which are currently widely used around the country to upgrade solid waste disposal facilities. It should be stressed, however, that the presentation given in this chapter is not directed at solving site specific problems, rather, it is presented as a generalized discussion of remedial techniques. For specific application to a Naval site, tests and individual engineering designs must be made to effectively implement the remedial technology.

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3.0 UNIT COST ESTIMATES FOR REMEDIAL ACTION TECHNOLOGIES

This chapter dicussses the costs associated with utilizing each of the upgrading techniques. The cost to the Navy for upgrading landfills occur in three phases, initial construction, operation and maintenance during the operating life of the fill, and perpetual cost following closure of the site. This list can be used to refine a cost estimate for a specific site. This chapter is divided into three sections to clearly illustrate the cost estimation proceed for landfill upgrading:

- o Unit cost development
- o Methodology for cost development
- o Cost estimation for each remedial technology

The cost estimates developed in this report were derived from three sources: Means Building Construction Cost Data, 1980; "Environmental Impact Statement: Criteria for Classification of Solid Waste Disposal Facilities and Practices (EIS)" U.S. EPA; and "Remedial Action Alternatives for Municipal Solid Waste Landfill Sites," by W. W. Beck, Jr., A. W. Martin Associates, Inc.

The Martin information, gathered in 1978, was escalated by a 12% per year inflation factor to bring costs up to date. The Means information and HETPA report were current and needed no modification.

Means data were used whenever possible for consistency. However, some activities and material with limited application to municipal landfills and waste disposal, or which were unavailable in Means, were obtained from one of the alternative sources.

Unit Cost Development

Unit Costs. Unit costs are the basic costs used in developing total costs for upgrading techniques. These costs are for individual operation, such as prepared gravel, which in combination with several operations make up the costs of permorming each remedial action. Unit costs are presented in cost/yard; this is accepted engineering practice, although not as common as cost/foot, but more closely approximate cost/meter soon to be employed. The unit cost value includes:

- o Overhead
- o Profit
- O Labor costs

Unit costs are based on the following premises:

- o A normal 8 hour working day (no overtime)
- o Material and machinery are available within 20 miles of the operation
- o National averages were used for all labor, equipment, and material costs.

Table 3-1 lists the unit costs for individual construction and Table 3-2 illustrates operating and maintenance costs for specific control technologies. These cost figures will be utilized in calculating the expenditures for each remedial technology.

TABLE 3-1: UNIT COSTS FOR CONSTRUCTION ACTIVITIES

ID #		DESCRIPTION	COST
1	A*	Unclassified Excavation	\$ 2.00- 4.50/yd^3
2	A	Classified Excavation - Solid Waste	\$ 5.25- 9.00/yd^3
3	A	Classified Excavation - Sediment Removal	2.00- 3.00/yd^3 \$ 2.00- 3.00/yd^3
4		Borrow Excavation - Rock	\$ 13.00- 23.00/yd^3
5		" " - Select Gravel	\$ 10.00- 16.00/yd^3
6		" " - Bank Run Gravel	\$ 5.00/yd^3
7		" " - Crushed Stone 3/4"	\$ 9.50/yd^3
8		" " - "Run of the Bank"	\$ 6.00/yd^3
9		" " - Earth	\$ 2.50- 5.00/yd^3
10		" " - Earth - Select	\$ 7.00/yd^3
11		" " - Native Clay	\$ 3.25- 6.00/yd^3
12		Rip-Rap Slope Protection	\$ 16.00/yd^3
13	A	Seeding and Mulching Erosion Protection	\$ .20- .35/yd^3
14	A	Diversion Ditch/Channel Excavation	\$ 8.00- 12.00/yd^3
15	A	Trench Excavation: 0-25 ft.	\$ 15.50- 25.00/yd^3
16	A	Trench Excavation: up to 80 ft.	\$ 20.00- 40.00/yd^3
17		Dragline Excavation 1½ yd^3 capacity	\$ 1.50/yd^3
18		Shovel Excavation 1½ yd^3 capacity	\$ 1.25/yd^3
19		Slurry Trench Excavation/Backfill	\$ 216.00-405.00/yd^3
20		Backfill - Dozer 300 h.p.	\$ .75/yd^3
21		Backfill - Rubber Wheel Loader	\$ .90/yd^3
22		Grading - Dozer 75 h.p.	\$ 2.50/yd^3
23		Grading - Dozer 300 h.p.	\$ 1.50/yd^3
24		Grading - Scraper towed 3 yd^3 capacity	\$ 1.75/yd^3
25	A	Grading - Fly Ash or Sludge	\$ 1.00- 1.75/yd^3
26		Compaction - Vibrating Plate	\$ 2.00/yd^3

*Unless otherwise indicated by letter A, B, C, cost figures were provided by Means Construction Cost Data, 1980.

TABLE 3-1: Con't.

ID #		DESCRIPTION	COST
27		Compaction - Wobble Wheel Roller	$ 1.50/yd^3
28		Compaction - Dozer with Roller	$ 1.25/yd^3
29		Dredging - Mobilization and Demobilization	$5,000.00-25,000.00
30		Barge Mounted Clamshell or Dragline. Excavation onto Scows	$ 5.50/yd^3
31		Barge Mounted Clamshell or Dragline. Hopper Dumped	$ 8.00/yd^3
32		Hydraulic Dredge - Pumped to Shore. Up to 1000 ft.	$ 3.00- 5.00/yd^3
33	B	Pressure Grouting: Sand: Cement 1:1 Mix	$ 337.50-648.00/yd^3
34	B	Bentonite Cement	$ 85.00-100.00/ton
35	B	Bentonite Slurry 65 lb/ft^3	$ 27.00- 33.75/yd^3
36	B	Portland Cement Grout	$ 5.25- 13.00/yd^3
37	B	Bituminous Concrete up to 5" Deep	$ 4.50- 6.00/yd^3
38		Synthetic Filter Fabric	$ 1.50/yd^2
39	B	PVC Membrane, 20 mil., Installed	$ 1.30- 2.00/yd^2
40	B	Chlorinated PE Membrane, 20-30 mil., Installed	$ 2.40- 3.20/yd^2
41	B	Elasticized Polyolefin Membrane, Installed	$ 2.70- 3.60/yd^2
42	B	Hypalon Membrane, 30 mil., Installed	$ 6.50/yd^2
43	B	Neoprene Membrane, Installed	$ 5.00/yd^2
44	B	Ethylene Propylene Rubber, Installed	$ 2.70- 3.80/yd^2
45	B	Butyl Rubber Membrane, Installed	$ 2.70- 3.80/yd^2
46		PVC Pipe - Class 160 S.D.R.-26	$ 2.00- 6.00/ft
47		Porous Wall Concrete Underdrain. STD Strength, 4" dia.	$ 2.50/ft

TABLE 3-1: Con't.

ID #		DESCRIPTION	COST
48		Vitrified Clay Sewer Pipe, 36" dia.	$ 64.00/ft
49		Vitrified Clay Pipe - Perforated	$ 3.70/ft
50		Corrugated Metal Pipe - Galvanized or Aluminum, 36" dia., 12 ga.	$ 28.00/ft
51	B	Paved Flume (Spillway)	$ 20.00- 30.00/yd^2
52	B	Sediment Pit, Trap	$ 500.00 ea.
53		Centrifugal Suction Pump 15-25 ft. lift, 4-5 gpm.	$ 300.00 ea.
54		Portable 3 h.p. Well Pump	$ 2,850.00 ea.
55		Jet Ejector Pump - 120 ft. lift, 5 gpm.	$ 750.00 ea.
56	B	4-inch Submersible Pump. 180 ft. lift, 23 gpm.	$ 1,175.00 ea.
57	B	2-inch Wellpoint	$ 22.50/ft
58	B	4-inch Wellpoint	$ 30.00/ft
59	B	Header Pipe - 6 inches	$ 35.00/ft
60	B	Header Pipe - 8 inches	$ 46.00/ft
61	B	Exploratory Boreholes, 2" dia.	$ 4.00- 13.00/ft
62	B	Monitoring Wells, 4" dia. - temporary	$ 8.00- 10.00/ft
63		Wells - Drilled up to 24" dia.	$ 15.00/ft
64		4" PVC Casing	$ 4.50/ft
65		6" PVC Casing	$ 6.50/ft
66	B	High Capacity Extraction Wells, Installed	$ 24.00- 40.00/ft
67		Well Caps	$ 250.00 ea.
68		Well Screens	$ 15.00/ft
69	B	Gas Probe Wells	$ 20.00- 28.00/ft

TABLE 3-1: Con't.

ID #		DESCRIPTION			COST
70		Concrete Seals and Test Equipment			\$ 250.00 ea.
71	B	500-2000 CFM @ 8" H_2O Fan			\$1,900.00-2,080.00
72		Gravity Concrete Retaining Wall 10 ft. high, 33^o surcharge			\$ 190.00/ft
73		Reinforced Concrete Cantilever Retaining Wall, 10' high, 33^o surcharge			\$ 150.00/ft
74		Buttressed Retaining Wall			\$ 11.00 S.F.C.A.
75		Galvanized Steel Fence, 10' high, 6 ga.			\$ 10.50/ft
76		Corner Posts			\$ 100.00 ea.
77		Sliding Gate, 45' long (pair)			\$ 2,000.00 ea.
78		Leachate Treatment to POTW, .1 MGD			\$ 25,000
79	B	Leachate Treatment, On-site, .1-.3 MGD			25,000.00-500,000.00
80	B	"	"	Activated Sludge with Clarifier	\$ 125,000-500,000
81	B	"	"	Ammonia Stripping	\$ 50,000-125,000
82	B	"	"	Aneorbic Facultative Lagoons	\$ 175,000-450,000
83	B	"	"	Biological Seeding with Activated Sludge	\$ 250,000-350,000
84	B	"	"	Carbon Adsorption l Regeneration	\$ 75,000-200,000
85	B	"	"	Chlorination	\$ 25,000- 75,000
86	B	"	"	Equalization	\$ 25,000- 75,000
87	B	"	"	Ion Exchange	\$ 200,000-500,000
88	B	"	"	Liquid Ion Exchange	\$ 200,000-500,000

TABLE 3-1: Con't.

ID #		DESCRIPTION		COST
89	B	Leachate Treatment, Precipitation/Floc Sedimentation	$	40,000-100,000
90	B	" " Pure Oxygen Activated Sludge	$	75,000-400,000
91	B	" " Rotating Biological Disc and Clarifier	$	75,000-500,000
92	B	" " Trickling Filter	$	75,000-200,000
93	B	" " Wet Air Oxidation	$	40,000-100,000
94	C	Soil Testing, Complete Series	$	216.00
95	C	Hydrometer analysis and specific series	$	60.00
96	C	Sieve Analysis, washed	$	8.00
		unwashed	$	50.00
97	C	Moisture Content	$	8.00
98	C	Permeability	$	50.00
99	C	Proctor Compaction	$	40.00
100		Concrete Pile Anchors	$	3.75/yd^3
101		Catch Basins	$	9,000.00 acre/ft
102		Geotechnical and Hydrological Testing	$	10,000.00
103		Suction Header (4" dia., no site work)	$	2.50-5.00/ft
104		Cement Plugs/Anchors - 3' x 3' x 3'	$	25.00 ea.

TABLE 3-1: Con't.

ID #	DESCRIPTION	COST
109	Non Regenerative Carbon Adsorption Systems - 2000 cfm	$ $ 35,000.00
110	Regeneration Carbon Adsorption Systems - 2000 cfm	$ 140,000.00
111	Small Ground Flaws - 2000 cfm	$ 25,000.00
112	Gas Recovery, installed, 1 million ft^3/day	$450,000.00-795,000.00
113	Support Posts, 3" dia., 15 ft.	$ 25.50/post
114	Wire Rope, 1/2" dia.	$ .75/ft.
115	Steel Braces, fence	$ 25.00/each

Sources

A - "Remedial Action Alternatives for Municipal Solid Waste Landfill Sites". W.W. Beck, Jr., A.W. Martin, Associates, Inc., 1978.

B - "Manual for Remedial Actions at Waste Disposal Sites". JRB Associates for U.S.E.P.A. Office of Solid Wastes, 1980.

C - Various industrial sources through personal communication with JRB Associates, Inc. personnel.

TABLE 3-2

OPERATION AND MAINTENANCE COSTS FOR IDENTIFIED TECHNOLOGIES

	Description	Average O&M Cost
5.1.1	Berms, Dikes and Levees	3.5% of initial capital cost
5.1.2	Floodwalls	4.0% of initial capital cost
5.1.3	Control of Backwater Flow	
	Dredging	9% of initial capital cost
	On-Shore Excavation	2% of initial capital cost
5.3.1	Ditches, Diversions and Waterways	6% of initial capital cost
5.3.2	Trenches and Benches	5% of initial capital cost
5.3.3	Chutes and Downdrains	5% of initial capital cost
5.3.4	Drainage Systems	7% of initial capital cost
5.3.4	Drainage Systems-Trenches	4% of initial capital cost
5.3.4	Drainage Systems-Recharge	2% of initial capital cost
5.3.5	Grading and Revegetation	3% of initial capital cost
5.3.6	Surface Capping	5% of initial capital cost
5.3.7	Sedimentation Ponds and Basins	4% of initial capital cost
5.3.8	Liners	5% of initial capital cost
5.4.1	Slurry and Clay-Filled Trench	2% of initial capital cost
5.4.2	Grouting	2% of initial capital cost
5.4.3	Subsurface Drains and Dewatering	5% of initial capital cost
5.4.3	Extraction Wells	6% of initial capital cost
5.4.4	Leachate Collection Systems	4% of initial capital cost
5.4.5 - 5.4.9	Leachate Treatment	15% of initial capital cost
5.4.10	Leachate Attenuation	6% of initial capital cost
5.4.11	Groundwater Monitoring	$400.00/sample + 1%/well of initial capital cost
5.7.1	Assessing Potential Gas Hazard	$700.00/sample + 1%/well of initial capital cost
5.7.1	Active Control Systems	8% of initial capital cost
5.7.1	Collection Removal and Venting	9% of initial capital cost
5.7.1	Venting and Disposal	7% of initial capital cost
5.7.3	Bird Hazards - Cable	4% of initial capital cost
5.7.4	Access - Fence	4% of initial capital cost

Unit Cost Variability. As stated previously, the unit costs used national averages for labor rates, materials, etc. When utilizing this unit cost information at a specific site, a number of variables must be considered which can influence costs, these include:

- Variations in wage rates
- Variations in worker productivity
- Variations in hydrogeology of the site
- Variations in site engineering
- Variations in material availability and cost
- Time of year during construction
- Weather variations
- Unscheduled overtime
- Availability of sufficient energy sources
- Availability of skilled labor force
- Local permitting costs
- Unforeseen engineering difficulties
- Use of Navy personnel which would be less costly than non-military labor
- Unused mobilization and demobilization expenses

Each of these variables can cause increases or decreases in the cost of construction and installation. These variables must be considered on an individual basis when estimating the costs at each site.

The unit costs presented in this chapter are provided to give the Navy an estimation of the individual costs in performing site upgrading. These costs are all reasonable general costs which should not be viewed as absolute for specific sites. Rather, with spiraling inflation and site idiosyncracies, each site should be evaluated by a design engineer before deriving an accurate cost estimate.

To facilitate the estimation and refinement of labor and equipment costs, Table 3-3 illustrates the crew required to perform each type of site upgrading construction and what the associated daily output would be of such a crew.

TABLE 3-3: CREW TYPE AND OUTPUT

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
A. Floodplains	1. Levee construction	2 drivers (heavy)		260.00
Perimeter levee		3 equipment operators		492.00
		1.5 building laborers		94.20
		2 heavy trucks (12 c.y.)	600 c.y.	442.00
		1 roller compacter	425 c.y.	58.00
		1 200 h.p. dozer	600 c.y.	430.00
		1 800 h.p. dozer	560 c.y.	633.40
A. Floodplains	2. Levee drainage	1 foreman		201.00
Perimeter levee	a. pipe	1 plumber		178.00
		1 building laborer	200 l.f.	126.00
	b. suction header	1 foreman		201.00
		1 plumber		178.00
		1 building laborer		126.00
		5 equipment operators (crane)		4.20
		5 self propelled (crane)	1/day	59.20
A. Floodplains	3. Erosion control	1 foreman		148.00
	a. vegetation	4 building laborers		502.00
		1 equipment operator (light)		155.20
		earthwork equipment (general)	200 l.f.	133.80
	b. rip-rap	1 equipment operator (crane)		168.40
		1 oiler		140.00
		1 crawler crane		220.00
		1 clam shell bucket ½ c.y.	62 c.y.	27.20

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
C. Surface Runoff	1. Ditch excavation and compaction	1 equipment operator		168.00
Drainage Bench		1 oiler		139.00
		1 hydraulic excavator 1 c.y.	1200 c.y.	331.00
		1 equipment operator		164.00
		.5 building laborer		62.80
		1 roller compactor 2000 lb.	125 c.y.	58.00
	2. Grading and paving	1 equipment operator		164.00
		.5 building laborer		62.00
		1 dozer 75 h.p.	160 c.y.	139.00
		1 foreman		148.00
		7 building laborers		879.00
		2 equipment operators		328.00
		1 paving machine		427.00
		1 roller 10 tons		114.00
C. Surface Runoff	1. Ditch excavation and	1 equipment operator		168.00
Diversion Ditch	compaction	1 oiler		139.00
		1 hydraulic excavator	1200 c.y.	331.00
		2 equipment operators		328.00
		1 building laborer		124.00
		1 dozer 75 h.p.	160 c.y.	139.00
		1 roller compactor	125 c.y.	58.00

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
C. Surface Runoff. Division Ditch	2. Erosion Control Vegetation	1 foreman		148.00
		4 building laborers		502.00
		1 equipment operator (light)		155.00
		earthwork equipment	1 Acre	133.80
C. Surface Runoff Leachate Interception	1. General excavation and trench preparation	1 equipment operator (crane)		168.00
		1 oiler		140.00
		1 crawler crane		306.00
		1 clam shell bucket	280 c.y.	36.00
		1 equipment operator		164.00
		1 building laborer		128.00
		1 hydraulic backhoe	200 c.y.	170.00
	2. Leachate Interception and collection system	2 truck drivers (heavy)		260.00
		1 equipment operator		164.00
		1.5 building laborers		186.00
		2 heavy trucks, 12 c.y.	600 c.y.	442.00
		1 dozer, 200 h.p.	600 c.y.	430.00
		2 foremen		402.00
		2 plumber		358.00
		2 apprentice		250.00
		2 special laborers (PVC membrane)	570 s.f.	320.00
		1.5 self propelled cranes	1 pump	84.00
		1.5 equipment operators		59.00
	3. Backfill and cover	1 equipment operator		155.00
		1.5 building laborers		186.00
		1 dozer, 75 h.p.	160 c.y.	139.00

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
C. Surface Runoff Leachate Interception	4. Erosion Control vegetation	1 foreman		148.00
		4 building laborers		502.00
		1 equipment operator		155.00
		earthwork equipment	1 Acre	134.00
D. Ground water Control Drainage Gradient	1. Grade and replace vegetation cover	2 equipment operators		336.00
		1 building laborer		125.00
		1 dozer, 75 h.p.	160 c.y.	139.00
		1 roller compacter	125 c.y.	58.00
		1 foreman		148.00
		4 building laborers		502.00
		1 equipment operator		155.00
		earthwork equipment	1 Acre	134.00
D. Ground water Control Surface sealing	1. Excavation, compaction, backfill and vegetation	2 truck operators		260.00
		3 equipment operators		492.00
		1.5 building laborers		186.00
		2 heavy trucks		442.00
		1 dozer, 200 h.p.	600 c.y.	429.00
		1 Tandom roller		56.00
		1 dozer, 200 h.p.	660 c.y.	430.00

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
D. Groundwater Control	1. General excavation	1 equipment operetor		168.00
		1 oiler		140.00
		1 crawler crane 25 ton		306.00
		1 clam shell bucket 1 c.y.	120 c.y.	36.00
	2. Trench excevation	2 equipment operetor		328.00
		2 truck drivers		260.00
		1.5 building laborer		94.00
		1 beckhoe loader	150 c.y.	170.00
		2 trucks 12 c.y.	600 c.y.	442.00
		1 dozer 200 h.p.	600 c.y.	430.00
	3. Drein line	1 foreman		201.00
		1 plumber		179.00
		1 building leborer	200 l.f.	126.00
	4. Backfill end compact	2 equipment operatore		328.00
		1 building laborer		121.00
		1 tandom roller		56.00
		1 dozer 200 h.p.	600 c.y.	429.00
D. Groundwater Excavation and Line	1. Generel excavation	4 equipment operators		656.00
		4 truck drivers		520.00
		1 oiler		140.00
		2 building laborers		252.00
		1 crewler crene 25 ton		306.00
		1 clam shell bucket		36.00
		1 front end loeder 1½		225.00
		1 dozer 200 h.p.	600 c.y.	430.00
		1 tendom roller 10 ton		114.00
		4 trucks	1200 c.y.	340.00

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
D. Groundwater Control	2. Capping	2 special laborers	570 s.f. membrane	320.00
Surface Sealing	PVC liner	earthwork equipment		134.00
	3. Capping	1 foreman		180.00
	Bentonite cement	4 laborers		628.00
		2 apprentices		236.00
		application equipment	350 s.f.	53.00
	4. Native clay soil	1 trench driver heavy		130.00
		1 hydraulic backhoe	150 c.y.	221.00
	5. Gas vents	2 equipment operators		328.00
		1.5 building laborers		186.00
		2 special laborera	570 s.f. membrane	320.00
		2 truck drivers.		260.00
		1 backhoe loader 80 h.p.	200 c.y.	170.00
		2 trucks 12 c.y.	600 c.y.	442.00
		1 dozer 200 h.p.	600 c.y.	430.00

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
D. Groundwater Control Excavation and Line	2. Under drain system	2 building laborers		252.00
		2 equipment operators		328.00
		2 heavy truck drivers		260.00
		2 special laborers	570 s.f.	320.00
		1 backhoe loader 30 h.p.	260 c.y.	170.00
		2 heavy trucks 12 c.y.	600 c.y.	442.00
		earthwork equipment	1 acre	134.00
	3. Re-fill	6 equipment operators		984.00
		4 building laborers		496.00
		4 truck drivers		520.00
		2 front end loader 1½ c.y.	1120 c.y.	450.00
		2 dozers 800 h.p.	1600 c.y.	1266.00
		4 heavy trucks 12 c.y.	1040 c.y.	340.00
		2 tandom rollers 10 ton		680.00
	4. Vegetation	1 foreman		148.00
		4 building laborers		502.00
		1 equipment operator		155.00
		earthwork equipment		134.00

TABLE 3-3: CREW TYPE AND OUTPUT (cont'd)

TECHNOLOGY	CREW FUNCTION	MINIMUM CREW COMPOSITION	DAILY OUTPUT	DAILY COST
G. Safety Gas Vents	1. Gravel filled vents	2 equipment operators		328.00
		1.5 building operators		186.00
		2 special laborers		320.00
		2 truck drivers		260.00
		1 backhoe loader 80 h.p.	200 c.y.	170.00
		2 trucks 12 c.y.	600 c.y.	442.00
		1 dozer 200 h.p.	600 c.y.	430.00
	2. PVC pipe added	1 foreman		201.00
		1 plumber		179.00
		1 building laborer		126.00
G. Safety Fences	Chain link	3 foreman		444.00
	Fence with sliding gate	6 building laborers		753.00

Methodology for Developing Site Upgrading Costs

The following is a discussion of the method used in developing the cost of each remedial action alternative. The steps involved in deriving unit cost estimates for identified control technologies are:

- o Determine facility dimensions
- o Outline construction activities
- o Outline equipment specifications
- o Derive cost/unit values
- o Calculate capital costs
- o Add 15% contingency factor
- o Add 9% engineering factor
- o Estimate annual cost by amortization
- o Estimate cost of perpetual care

The methodology is presented below using the various costs as milestones and detailing the steps necessary to arrive at these costs.

A. Derive Estimated Capital Cost

1. Determine appropriate remedial technology (i.e., perimeter levee)

2. Determine task outline necessary for completion (i.e., excavation, borrow excavation, grading, erosion control)

3. Determine scope of facilities and dimensions of necessary activities (i.e., 10' high x 600' long with underdrain system).

4. Determine appropriate cost/unit measure (i.e., cost/linear yard of levee).

5. If necessary, determine cost/linear yard for each activity by multiplying cost/unit measure by appropriate multiplier.

   i.e. $\dfrac{\$6.00}{\text{yd.}^3 \text{ of borrow excavation}} \times \dfrac{31.9 \text{ yd}^3 \text{ of borrow needed}}{\text{yd of levee}}$

   = \$191.40/yd. of levee

6. If necessary, determine amount of earthwork or equipment needed to complete linear yard (i.e., amount of excavation necessary/yard of levee or 31 yd^3 of fill needed/linear yard of levee).

7. Determine costs/task by multiplying cost/unit measure (or cost/linear yard) by amount of needed construction for each task.

   i.e. $\dfrac{191.40}{\text{yd of levee}}$ X 200 yd of levee = \$38,280 for borrow excavation

8. Determine estimated capital costs by totaling costs/task.

   Levee Construction

i.e.	\$38,280.00	- borrow excavation
	5,670.00	- excavation
	9,570.00	- grading
	9,570.00	- compaction
	7,200.00	- vegetation
	\$70,290.00	- for levee 600' long x 10' high

Underdrain System

$1,500.00 - underdrain
3,000.00 - suction header

Erosion Control

$ 934.00 - seeding & mulching

9. Determine replacement costs for any equipment with a lifespan which is less than the life of the landfill.

B. Derive Total Capital Costs

1. Total estimated capital costs for each activity.

$70,290	for levee
4,500	for drainage system
934	for erosion control
$75,724	

2. Add 15% contingency factor

$75,724	
11,358	- 15%
$87,082	

3. Add 9% engineering factor to total capital costs.

$87,082	
7,837	- 9%
$94,919	

C. Determine Annual Operation and Maintenance Costs

1. Erosion control and re-filling of levee where needed.

   3.5% of initial capital cost

   $94,919 x 0.035 = $3,322

D. Determine Unique One-Time Costs

1. Costs for permitting such as NPDES permits. Costs vary from state to state, costs range from $5,000.00 to $10,000.00

E. Determine Cost for Perpetual Care

A final factor in estimating the cost of upgrading solid waste disposal is the cost of perpetual care. This includes both O&M costs and equipment replacement costs. The Navy is responsible for maintaining each of their landfills after closure. In addition to closure costs, there are several upgrading techniques which will require maintenance following site closure. The following is a discussion of those remedies which will require continued operation after landfill closure, the average length of continued operation and the associated costs of perpetual care:

- Leachate collection, operate for approximately 15 years following landfill closure. The pumps will have to be overhauled after 7 years at a cost of approximately $5,000.00. Associated with leachate collection is an annual cost of $1,000.00 for operation and maintenance of the pipes.

- Leachate treatment, involves approximately $5,000.00 per year in operation and maintenance costs for the system. Leachate treatment would on the average continue for 15 years following landfill closure.

- Groundwater monitoring wells, monitoring of the groundwater will generally continue for 20 years following landfill closure, the wells should be sampled approximately 4 times per year at a cost of $400.00 per analysis, or $1,600.00 per year per well.

- Methane monitoring wells should be monitored approximately four times a year, in some situations such as proximity to school, they should be monitored six times per year or more. Samples cost $600.00 each and sampling should continue for 20 years.

- Levees, the cost of perpetual care for a levee is affected by the frequency of flooding. Although a levee will withstand a 100 year flood, it will require extensive repair following floodwater recession.

- Drainage benches, will require operation and maintenance costs of $1,000.00 per year, estimating that 25 percent of the bench will be regraded each year.

- Drainage ditches, acrue approximately $1,000.00 per year in operations and maintenance costs for re-excavation.

Cost Estimation for Remedial Technology

This section identifies remedial technologies and associated costs for implementing each of those technologies.

An explanation of the format used to present the unit costs follows.

3.1 = *The number corresponds to the same section in Chapter 2 This identifies the criteria the remedial activity is designed to address.*

3.1.1 Berms and Dikes - *This identifies the particular remedial technology to be discussed.*

Assumptions - *Any assumptions made about physical parameters, material availability or system design will be listed here.*

Description - *A general description of the remedial technology along with physical values will be provided.*

Multipliers - *Multipliers convert physical dimensions to desired units will be derived in this section.*

Construction Costs

ID# - *This # corresponds to the identifying # in Table 3-1.*
Description of Activity - *The type of activity will be listed here.*
$/Unit - *Unit costs as they appear in Table 3-1.*
Multiplier - *The appropriate multiplier to change $/unit to $-costs/ desired unit will be listed here.*
$Costs/Unit - l.yd. - *The desired unit, in this case linear yards, will be listed in this section. Changing $/unit to $-costs/unit through multipliers is designed to make comparisons among remedial technologies easier.*

In many cases, unit costs could not be derived because the technology was too dependent on site specific data. Included in this category were:

3.2.1 Protecting Endangered Species
3.2.2 Selective Landfilling
3.2.3 Mitigation Landfilling

3.5.1 Sewage Sludge, Septic Tank Pumping
3.5.2 Controlling Vectors
3.5.3 Controlling Rodents
3.5.4 Controlling Misquitos
3.5.5 Controlling Health Hazards

3.6.1 Controlling Fires
3.6.2 Controlling Dust

Because of the inability to derive appropriate unit costs for these technologies, they were not included in the following sections. However, for ease of understanding and to facilitate comparison with the appropriate sections in Chapter 2, the section numbers were retained even though unit costs are not available. The designs for the remedial alternatives were based on the appropriate discussion in Chapter 2. It is suggested that before reading the unit costs, Chapter 2 be read to provide a general understanding of the remedial action.

3.1 FLOODPLAINS

3.1.1 Berms, Dikes or Levees - New Construction -

Assumptions:	1) 100 yr. flood = 10 ft. above datum
Description:	Height of Levee = 10 ft.
	Forward Slope = 40' with 1:4 slope
	Rear Slope = 20' with 1:2 slope
	Base Length = 56.5'
	Underdrain system of porous concrete
	Erosion control, either vegetation or rip-rap, depending on expected annual flood. (See Chapter 4, Section 4.-1.)
Multipliers:	Area of Forward Slope = 13.33 sq.ft./linear yd. of levee
	Volume of Levee = 31.9 yd^3/linear yd. of levee

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COSTS/UNIT-L.YD.
	LEVEE CONSTRUCTION			
1	Unclassified Excavation 1' strip under levee	2.00-4.50/yd^3	6.3yd^3/yd	12.60-28.35
11	Borrow Excavation - native clay	3.25-6.00/yd^3	31.9	103.70-191.40
23	Grading at site - 300hp dozer	1.50/yd^3	31.9	47.85
27	Compaction - wobble wheel roller	1.50/yd^3	31.9	47.85
				$212.00-315.50
	UNDERDRAIN SYSTEM			
47	Porous wall concrete underdrain, 4" diameter - installed	2.50/ft.	3	7.50
103	Suction Header, installed	2.50-5.00/ft	3	7.50-15.00
				$15.00-22.50
	EROSION CONTROL			
13	Seeding and Mulching	.20-.35/yd^2	13.34	2.67-4.67
12	Rip-Rap Slope Protection	16.00/yd^2	13.34	$213.44

TOTAL COSTS

LEVEE CONSTRUCTION	$212.00	-	315.50
Underdrain System	15.00	-	22.50
Erosion Control - Vegetation*	2.67	-	4.67
	$229.67	-	342.67
9% Eng. cost	20.67	-	30.80
	250.34	-	373.51
15% Contingency Cost	37.55	-	56.03
	$287.89	-	429.54/linear yd. of levee

*If Rip-Rap Control, Final Cost = $466.44 - 60[illegible].08/linear yd. of levee

3.1.1 Berms, Dikes or Levees, (Cont.)

Discussion of impervious core construction or sheet pile wall construction were not included as these technologies are specialized and only applicable in very rare instances. As such, the site specific nature of the technology makes unit cost development impractical and the specialized use of these technologies makes it highly unlikely that they will be needed at any solid waste disposal facility.

3.1 FLOODPLAINS

3.1.2 Floodwalls

Description: 10ft. high
2-10% initial slope,
no solid waste excavation necessary
33° surcharge

Multipliers: Excavation included in total price along with Engineering costs. 15% contingency costs must be added.*

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COSTS/UNIT-L.YD.
72	Gravity concrete wall with excavation and backfill	$190.00/ft.	3	570.00
73	Reinforced concrete with excavation and backfill	150.00/ft.	3	450.00
74	Butressed wall with excavation and backfill	11.00/SFCA**	30	330.00
2	Classified Excavation - Solid Waste	5.25-9.00/yd^3		5.25 - 9.00/yd^3
15	Trench Excavation, 0-25 ft deep	15.50-25.00/yd^3		15.50 - 25.00/yd^3

*Detailed Engineering designs must be made for each site due to the wide variances in expected load, soil bearing strength, etc. The unit costs given for the various types of floodwalls, Numbers 72, 73, 74, reflect this added cost in their cost/linear yard figures. The 15% contingency fee, however, is not included in the unit costs. Site preparation costs and other added costs could not be included due to their site specific nature.

**SFCA = Square Foot Contact Area

3.1 FLOODPLAINS

3.1.3 Control of Backwater Flow

Description: Dredging and Channel Improvements on site specific basis. Borrow Pits where needed.

Multipliers: Not applicable due to site specific nature of activities. Costs listed in yd^2 or yd^3.*

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITIES	$COSTS/UNIT - YD^3
1	Unclassified Excavation	2.00-4.50
29	Dredging-Mobilization and Demobilization add to 30, 31, 32.	5,000-25,000 each
30	Barge Mounted Clamshell or Dragline excavation into scows.	5.50
31	Barge Mounted Clamshell or Dragline Hopper dumped	8.00
32	Hydraulic Dredge pumped 1000 ft. to shore	3.00-5.00
17	Dragline (on-shore) 1½ cy capacity**	1.50
18	Shovel (on-shore) 1½ cy capacity***	1.25

*The dredging of areas to increase backwater flow is dependent entirely on local conditions including bank type, river flow and velocities, type of soil and vegetation, etc. Due to these factors, more detailed unit costs could not be derived. Instead, expected costs/unit of the various activities are listed. Once the type of dredging required is known and the amount and type of excavation known, the above unit costs can be used to arrive at expected capital costs.

**Dragline where conditions are suitable for operations.

***Shovel in near pool areas or along banks.

3.2 ENDANGERED SPECIES

3.2.1 Protecting Endangered Species - Unit costs not available. See Page 3-6.

3.2.2 Selective Landfilling - Unit costs could not be determined. See Page 3-6.

3.2.3 Mitigation Land - Unit costs could not be determined. See Page 3-6.

3.2.4 Dry or Vertical Landfilling - Unit costs could not be developed due to the site specific nature of the technology. Specifically, the amount, extent and cost of constructing the base of the fill and adjoining structures is so dependent on the soil characteristics as to make the development of general unit costs impractical. Detailed geologic, hydrologic and engineering studies are necessary before a determination of costs on a site specific basis can be determined.

3.3 SURFACE WATER

3.3.1 Ditches, Diversions, and Waterways

Description: 10' wide at top, slope in 2:1 to 2' wide at botton of ditch
Total depth - 2'
Vegetation to control erosion and provide stabilization

Multipliers: Volume of excavated trench/linear yard-1.34yd^3.
area of excavated trench/linear yard-1.24yd^2.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COSTS/UNIT L.YD.
14	Diversion Ditch/excavation	8.00-12.00/yd^3	1.34yd^3/yd	10.72-16.08
13	Seeding and Mulching	.20-.35/yd^2	1.23yd^2/yd	.25-.43
23	Grading at Site-Dozer 300hp*	1.50/yd^3	1.34yd^3/yd	2.01
28	Compaction at Site**	1.25/yd^3	1.34yd^3/yd	1.68
				$ 14.66-20.20

TOTAL COSTS

Excavation and erosion control	$ 14.66 - 20.20
9% engineering cost	1.32 - 1.82
	$ 15.98 - 22.02
15% contingency cost	2.40 - 3.30
	$ 18.38 - 25.32/Linear Yard

Estimated cost of ditch construction/linear yard = $18.38-$25.32

* Grading necessary to increase up or down slope gradient if excavated material to be disposed of on-site. Disregard if material to be used as Borrow.

** Compaction necessary if material to be used on site, and if necessary in trench, depending on soil type.

3.3 SURFACE WATERS

3.3.2 Trenches and Benches

Assumptions: Trench to be used where high velocity is expected on regular basis.

Description: Bench 6' wide at top, sloping 2:1 to bottom. Depth 1.5', upslope berm graded to 10% minimum Bituminous or concrete layer 3" minimum

Multipliers: Volume of excavated trench/linear yard=5yd^3/yd
Area of trench site/linear yard=.75yd^2/yd.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COSTS/UNIT-L.YD
14	Diversion Ditch/Unclassified Excavation	8.00-12.00/yd^3	.5yd^3/yd	4.00-6.00
37	Bituminous Concrete* 3" deep=.19yd^3/l.yd	4.50-6.00/yd^3	.19yd^3/yd	.85-1.15
28	Compaction - Dozer Roller**	1.25/yd^3	.5yd^3/yd	.63
				$ 5.48 - 8.13

TOTAL COSTS

Excavation and Erosion Control	$ 5.48 - 8.13
9% Engineering Costs	.49 - .73
	$ 5.97 - 8.86
15% Contingency Costs	.90 - 1.33
	$ 6.87 -10.19/Linear yard

Estimated Costs of Trench/Bench/Linear Yard = $6.90 - $10.20

* Bituminous Concrete used where high average flow expected to reduce erosion. Where average expected flow low, vegetative erosion control is feasible. Use $.20-$.35/yd^2, ID# 13, in place of given values. New estimated cost = $6.00-$9.20/l.yd.

** Compaction necessary to prepare surface for paving and to construct designed up-or downslope gradients.

3.3 SURFACE WATERS

3.3.3 Chutes and Downdrains

Description: Chute - Bottom 10 ft. wide, depth 1 ft., sides sloped 1.5:1 sides = 1.8 ft. long. Bituminous concrete paved 2"deep.

Multipliers: Volume of chute/linear yard = 1.2 yd^3/yd.
Surface area of chute/linear yard = 4.5 yd^2/yd.
Bituminous layer = .25 yd^3/yd.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITIES	$COST/UNIT	MULTIPLIER	$COSTS/UNIT L.YD.
1	Unclassified Excavation	2.00-4.50/yd^3	1.2 yd^3/yd	2.40- 5.40
28	Compaction-dozer with roller	1.25/yd^3	1.2 yd^3/yd	1.50
37	Bituminous Concrete	4.50-6.00/yd^3	.25	1.13- 1.50
			Construction costs	$ 5.03- 8.40
			9% engineering costs	.46- .76
				$ 5.49- 9.16
			15% contingency costs	.83- 1.37
				$ 6.32-10.53

Estimated cost/linear yard of chute = $6.30-10.50/yd

Description: Downdrains - Corrugated pipe through earth.
Dike emptying into riprap protection.
Drain, 36" diameter, 12 ga. galvanized corrugated metal.
Reinforced concrete through earth dike.

Multipliers: Volume excavated/linear year = .5 yd^3/yd
Rip Rap = 6' x 6' x 2' = .9 yd^3/yd*

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITIES	$COST/UNIT	MULTIPLIER	$COST/UNIT L.YD.
1	Unclassified Excavation	2.00-4.50/yd^3	.5 yd^3/yd	1.00- 2.25
50	Corrugated Metal Pipe	28.00/ft	3	84.00
48	Concrete Reinforced Pipe	64.00/ft	3	192.00
12	Rip Rap Erosion Control	16.00/yd^3	.9	14.40

Estimated Costs	$Cost/Unit
Downdrain Construction	85.00-86.26/yd (Not including 9% and 15% Factors).
add to total cost	192.00/yd of concrete reinforced pipe 14.40 for erosion control

*Rip-Rap to prevent scouring when downdrain empties on lower levee.

3.3 SURFACE WATER

3.3.4 Drainage Systems

Description: 4" perforated PVC pipe laid in trench 1½ x 6'. Trench filled with drain rock. Trenches laid out along landfill perimeter or in cross-hatch pattern throughout landfill when feasible (usually in planned or newly opened areas of the fill). PVC pipes to drain into toe collection header or sump.

Multipliers: Costs given in yd^3 or yd^2 due to site specific nature of amount of necessary excavation. For new areas where extensive excavation not necessary, multipliers are:

Volume of Trench/Linear Yard = 1 yd^3/yd

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY		$COSTS/UNIT ($YD^3$)
	Remove Cover Soil and Refuse*		
1	Unclassified Excavation		2.00- 4.50
2	Classified Excavation-solid waste		5.25- 9.00
			7.25-13.50
	Trench Construction	Multiplier	$Costs/Unit (l.yd)
15	Trench Excavation-up to 25' deep.	1 yd^3/yd	15.50-25.00
7	Gravel fill, crushed stone 3/4"	1 yd^3/yd	9.50
46	PVC pipe, class 160, perforated 2.00-6.00/ft	3 ft/yd	6.00-18.00
103	Suction Header, installed 2.50-5.00/ft	3 ft/yd	7.50-15.00
	Estimated Drainage Trench Costs		38.50-67.50
	Replace Cover Soil and Refuse**		
20	Backfill - dozer 300 h.p.		.75/yd^3
28	Compaction - dozer with roller		1.25/yd^3
9	Borrow Excavation, earth		2.50- 5.00/yd^3

*Cost of excavation through completed sections of landfill will be closer to $5.25-9.00/yd because of mixing occurring during daily operations. Cost of unclassified excavation used when thick final cover has been added.

3.3.4 Drainage Systems (Continued)

**New final cover necessary after trench filled in. Compaction with dozer necessary to prevent sinking after trench backfilled. Width of trench should be capable of permitting compacting operations after PVC drain installed and during backfilling.

3.3 SURFACE WATER

3.3.4 Drainage Systems - Trenches

Description: Gravel filled trench (3 ft. wide x 10 ft. deep) lined with filter of synthetic material.

Multipliers: Volume of trench/linear year = 3.34 yd^3/yd
Area of trench walls/linear yard = 7.67 yd^2/yd

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTIPLIER	$COSTS/UNIT L.YD.
15	Trench Excavation*	15.50-25.00/yd^3	3.34	51.77- 83.50
38	Synthetic filter	1.50/yd^2	7.67	11.50
7	Gravel filled, crushed stone 3/4"	9.50/yd^3	3.34	30.73
20	Backfill - dozer 300 h.p.	.75/yd^3	3.34	2.50
				$ 96.50-128.23
	For Drainage Pipes			
47	Porous wall concrete underdrain (perforated) with filters.	$ 2.50/yd		

TOTAL COSTS

Trench construction	$96.50-128.23
9% engineering cost	8.68- 11.54
	$105.18-139.77
15% contingency cost	15.77- 20.97
	$120.95-160.74/linear yard of trench

For concrete underdrain - add $2.50.
For catch basins - add $9,000/acre-foot.

*Trench excavation necessary due to need for labor in trench necessitating shoring and stabilization. If trench to be less than 9 ft. deep, cost of trench excavation reduced to 2.00-4.50/yd^3 - total costs of system without drain would be approximately $64.00-$75.00/yd of trench.

3.3 SURFACE WATER

3.3.4 Drainage Systems - Recharge Basins

Description: Seepage Pit with sediment trap and bypass flow. Cost for yd^3 of pit plus fixed costs for sediment traps, etc.

Multipliers: Costs given in yd^2 or yd^3 due to site specific factors. Hydrological studies needed to determine amount of recharge needed.

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTIPLIER	$COSTS/UNIT($YD^3$)
1	Unclassified excavation	2.00-4.50/yd^3	1	2.00-4.50/
8	Gravel fill	6.00/yd^3	1	6.00/
52	Sediment pit (pre-cast)	500.00 ea.	1	500.00 ea.

TOTAL COSTS (yd^3) (Not including 9% and 15% factors)

Pit Excavation and Fill	8.00-10.50/yd^3
Plus Sediment Pits (Pre-Cast)	500.00 ea.

3.3 SURFACE WATERS

3.3.5 Grading and Revegetation

Description: Minimum slope, 2%; maximum, 30%.

Multipliers: Costs given in yd^3 or yd^2 due to site specific nature of activities making further reduction of units impossible.*

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$COSTS/UNIT($YD^3$)
22	Grading - dozer 75 h.p.	2.50
23	Grading - dozer 300 h.p.	1.50
27	Compaction - wobble wheel roller	1.50
28	Compaction - dozer with roller	1.25
9	Borrow Excavation - earth	2.50-5.00
13	Seeding and Mulching	.20- .35/yd^2

*The type and amount of regrading and revegetation is dependent on initial grade, annual precipitation, soil type, existing revegetation and normal operating procedures at the site. These site-specific costs make deriviation of unit costs impractical.

3.3 SURFACE WATERS

3.3.6 Surface Capping

Description: Variable, clay or suitable synthetic liner with gas vents and surface water controls. For discussion of gas vents, see sections 2.7.1 - Safety, and 3.7.1 - Gas Vents.

Multipliers: Costs given in yd^3 or yd^2 due to site specific nature of amount of necessary activities.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$COSTS/UNIT
1	Unclassified Excavation	2.00- 4.50/yd^3
2	Classified Excavation - solid waste	5.25- 9.00/yd^3
9	Borrow Excavation, earth	2.50- 5.00/yd^3
28	Compaction - dozer with roller	1.25/yd^3
34	Bentonite Cement	85.00-100.00/ton
37	Bituminous Concrete - up to 5" deep*	4.50- 6.00/yd^3
39	PVC Membrane, 20 mil., installed*	1.30- 2.00/yd^2
40	Chlorinated PE Membrane, 20-30 mil., installed*	2.40- 3.20/yd^2
25	Fly Ash and Sludge (spreading)**	1.00- 1.70/yd^2
13	Seeding and Mulching	.20- .35/yd^2

*The use of chemical or leachate damage resistant membranes is not recommended as surface caps are designed to deter surface and rainwater infiltration and should not be exposed to chemicals, etc. PVC after covering is considered more than adequate for most landfills given proper operating procedures.

**Fly ash and sludge, while having many advantages, have many disadvantages (i.e., heavy metals contamination). Use as a surface cap should be carefully studied prior to implementation.

3.3 SURFACE WATER

3.3.7 Sedimentation Ponds and Basins

Description: Earthen dike damming downslope drainage channel prior to entry into waterway. Structures include principal spillway with riser along with emergency spillway. Alternate design consists of single excavated basin with outflow to running water.

Multipliers: Costs will be derived on per structure basis. Approximately .2 acre-feet/acre disturbed needed for storage.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$COSTS/UNIT	MULTIPLIER	$COSTS/UNIT
1	Unclassified Excavation	2.00-4.00/yd^3	1613.3 yd^3/ acre-foot	3225.00-6450.00 acre-foot
23	Grading - dozer 300 h.p.	1.50/yd^3	1613.3 yd^3/ acre-foot	2020.00/acre-ft.
28	Compaction - dozer with roller	1.25/yd^3	1613.3 yd^3/ acre-foot	2020.00/acre-ft.
			Construction Costs	$7665.00-10,890.00
			9% Engineering Cost	690.00- 980.00
				$8355.00-11,870.00
			15% Contingency Cost	1253.00- 1,780.00
			Estimated Cost/acre-foot =	$9608.00-13,650.00

	Construction Costs - Additional	$Costs/Unit
51	Paved Flume, (spillway) installed	20.00-30.00/yd^2
12	Rip Rap Impact Structure	16.00/yd^3
13	Seeding and Mulching	.20- .35/yd^2
3	Sediment Removal from Basin	2.00- 3.00/yd^3

3.3 SURFACE WATERS

3.3.8 Liners

Description: Containment liners for total isolation and collection of leachate. Liner to be placed under landfill area prior to operations. Liner to be overlain with approximately 2 to 3 feet of suitable material to prevent puncture.

Multipliers: Unit costs given in yd^2 or yd^3 due to site specific nature of technology. Site cost has been derived on per acre basis assuming 2 $\frac{\text{acre-ft}}{\text{acre}}$ necessary for excavation to provide suitable surface.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTIPLIER	$COSTS/UNIT (ACRE)
	Unclassified Excavation	2.00-4.50/yd^3	3227 yd^3/acre	6454.00-14,521.50
28	Compaction - Dozer With Roller	1.25/yd^3	3227 yd^3/acre	4,034.00
21	Backfill - Rubber Wheel Loader	.90/yd^3	3227 yd^3/acre	2,904.00
26	Compaction - Vibratory Plate	2.00/yd^3	3227 yd^3/acre	6,454.00
10	Borrow Earth - Select*	7.00/yd^3	1615 yd^3/acre	11,305.00

TOTAL COSTS - Site Preparation

Construction Costs	$19,846.00 - 39,218.00/acre
9% Engineering Costs	1,786.00 - 3,530.00/acre
	$21,632.00 - 42,748.00/acre
15% Contingency Costs	3,245.00 - 6,412.00/acre
	$24,877.00 - 49,160.00/acre

Unit Costs - Material**

	Butonite, 2" layer spread and compacted	1.40/yd^2
39	PVC, 20 mil., installed	1.30-2.00/yd^2
40	Chlorinated PE, 30 mil., installed	2.40-3.20/yd^2
41	Elasticized polyolefin membrane, installed	2.70-3.60/yd^2
42	Hypalon membrane, 30 mil., installed	6.50/yd^2
43	Neoprene membrane, installed	5.00/yd^2
44	Ethylene propylene rubber, installed	2.70-3.80/yd^2
45	Butyl rubber membrane, installed	2.70-3.80/yd^2

* If native material suitable for top protective layer, subtract this cost from estimate.

** "Installed" includes transport to site, membrane laying and sealing, and final testing. Cost does not include initial or final site preparation.

3.3 SURFACE WATERS

3.3.9 Control of Leachate Seepage

No unit costs for control of leachate seepage were derived since the technology is identical to 3.3.4, Drainage Systems, except on a limited scale. Unit costs for 3.3.9, Control of Leachate Seepage, are therefore the same. See Section 2.3.9, for further discussion.

3.4 GROUNDWATER

3.4.1 Slurry and Clay - Filled Trenches

Description: Trench 20 ft x 6 ft filled with either bentonite slurry and backfilled or with compacted clay. Trench needs reinforcing when clay is to be used.

Multipliers: Volume of trench/linear yard = 13.34 yd^3/yd.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTIPLIER	$COSTS/UNIT (L.YD)
19	Slurry Trench Excavation and Backfill	216.00-405.00/yd^3	13.34	2881.44-5402.70
TOTAL COST with 9% engineering and 15% contingency			=	3661.00-6771.00
	Clay Trench			
15	Trench Excavation, 0-25 ft.	15.00- 25.00/yd^3	13.34	206.77- 333.50
11	Borrow Excavation, native clay	3.25- 6.00/yd^3	13.34	43.35- 80.00
28	Compaction, roller (clay)	1.25/yd^3	13.34	16.68
23	Grading, Excavated earth	1.50/yd^3	13.34	20.00
				286.80- 450.20

TOTAL COSTS

Trench Excavation and Backfilling	$286.80-450.20/l.yd.
9% Engineering Costs	25.81- 40.52/l.yd.
	$312.61-490.72/l.yd.
15% Contingency Costs	46.89- 73.61/l.yd.
	$359.50-564.33/l.yd.

3.4 GROUNDWATER

3.4.2 Grouting

Description: Portland Cement Grout used, 2 Rows, radius, 2.5'; centers 5' apart; depth 60 ft, porosity = 25%

Multipliers: Volume to be grouted/linear yard = 66.67 yd^3/yd
Volume of grout/yd^3 = .25 yd^3 grout/yd^3

CONSTRUCTION COSTS

ID #	DESCRIPTION OF ACTIVITY	$/UNIT	MULTIPLIER	$COSTS/UNIT
33	Pressure Grouting 1:1 Mix Sand and Cement	337.50-648/yd^3	66.67 ·.25	5625.00-10,800.00 / Linear yard
102	Geotechnical and hydrologic testing			$10,000-30,000 ea.

TOTAL COSTS

Grout Curtain Construction	$5625.00-$10,800.00/l.yd.
9% Engineering Costs	506.25- 972.00
	$6131.25-$11,772.00
15% Contingency Costs	919.69- 1,765.80
	$7050.94-$13,537.80/l.yd.

Add to Total

Geotechnical and hydrologic testing - $10,000.00-$30,000.00

Unit Costs for Grout Types*

Grout type		$/gal
Portland cement	-	.95
Bentonite	-	$1.25
Silicate - 20%	-	$1.75
30%	-	$2.10
40%	-	$2.75
Lignochrome	-	$1.55
Acrylamide	-	$6.65
Urea Formaldehyde	-	$5.70

*Source: Various industry contacts and in-house studies.

3.4 GROUNDWATER

3.4.3 Subsurface Drains and Dewatering Systems
Subsurface Drains

Description: Vitrified clay pipe (perforated), 6" diameter surrounded by gravel. Trench 21' deep, 3 feet wide. System to include pump and piping but not treatment. Impermeable clay barrier trench 21'x 3'x 3'.

Multiplier: Volume of trench/linear yard = 7.00 yd^3/yd
Volume of clay trench/linear yard = 7.00 yd^3/yd

CONSTRUCTION COSTS

ID #	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COSTS/UNIT (L.YD.)
15	Trench Excavation, 0-25 ft	15.50-25.00/yd^3	7	108.50-175.00
49	Vitrified Clay, perforated, 6" dia. - minimum	3.70/l.ft.	3	11.10
7	Gravel Fill, crushed stone, 3/4"	9.50/yd^3	7	66.50
1	General Excavation, Clay Trench*	2.00- 4.00/yd^3	7	14.00- 28.00
11	Borrow Excavation, Native Clay*	3.25- 6.00/yd^3	7	22.75- 42.00
				228.82-322.60

Construction Costs - additional

53	Centrifugal pump**, 4-5gpm	$300.00 each
	Additional piping and fixtures/ pump	$ 12.00/yd plus $250.00/pump for seat and accessories
60	8" Header pipe	$ 46.00/foot

* Clay barrier trench can be omitted in areas of low permeable soil or where geologic testing shows low groundwater flow.

**Number of pumps and spacing must be determined on site specific basis. Individual centrifugal pumps may not be feasible where large system is needed and in areas of expected high flow.

3.4 GROUNDWATER

3.4.3 Extraction Wells and Wellpoint Systems

Description: Unit costs are provided. Total costs cannot be determined due to site specific nature of necessary activities.

Multipliers: N/A*

ID #	DESCRIPTION OF ACTIVITY	$/UNIT
57	2 inch Wellpoint	$22.50/ft + $15 for fittings
59	Header Pipe - 6 inches	$35/ft.
58	4 inch Wellpoint	$30/ft + $28 for fittings
60	Header Pipe - 8 inches	$46/ft
53	Centrifugal Suction Pump	$300.00 ea.
55	Jet Ejector Pump - 120 ft. Lift; 5 gpm; 3/4 h.p.	$750.00 ea.
56	4 inch Submersible Pump - 180 ft. Lift; 23 gpm	$1,175.00 ea.
62	Monitoring Wells - 4 inches	$8.00-10.00/ft
64	4 inch PVC Casing	$4.50/ft
65	6 inch PVC Casing	$6.50/ft
66	High Capacity Extraction Wells; construction and installation	$24.00-40.00/ft

* Groundwater extraction wells and well point systems are dependent on site specific characteristics in terms of size, extent, capacity and difficulty of installation. Subsequently, derivation of general unit costs for complete systems is not practical without site specific data.

3.4 GROUNDWATER

3.4.4 Leachate Collection Systems

Description: Perforated pipe in gravel filled trench. 3' x 3'. Pipe leads to at least 1 pump for discharge to treatment.*

Multipliers: Volume of trench/linear yd = 1 yd^3/yd

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COST/UNIT (L.YD.)
1	Unclassified Excavation	2.00-4.50/yd^3	1 yd^3/yd	2.00-4.50
49	Vitrified Clay Pipes - perforated	3.70/ft	3 ft/yd	11.10
7	Gravel Fill - 3/4" crushed stone	9.50/yd^3	1	9.50
53	Centrifugal suction pump	300.00 ea.		300.00 each
60	Header pipe - 8"	46.00/ft	3	138.00

TOTAL COSTS

Drain Construction $22.60-25.10/yd with 9% + 15% factors

Add to total -

Pump $300.00/each

Header pipe $138.00/yd

*Number and rated capacity must be determined by engineer and hydrologist after on-site evaluation of expected flow. In general, the specification for pipes and dimensions of the trench should be adequate for most facilities.

3.4 GROUNDWATER

3.4.5-3.4.9 Leachate Treatment - On-Site Treatment

Description: Costs for pumping and routing systems are included along with site preparation.

Multipliers: Due to site specific nature of the technology, unit costs could not be determined. Industry costs for existing plants are given instead. Minimum costs usually $20,000.00-$25,000.00.

Costs - Treatment Modules - 100,00-300,000 g/day

ID#	DESCRIPTION OF ACTIVITY	COSTS x $1,000
80	Activated Sludge Treatment with Clarifier	125-500
81	Ammonia Stripping	50-200
82	Anaerobic Faculative Lagoons	175-450
83	Biological Seeding with Pure Oxygen Activation	250-300
84	Carbon Adsorption with 1 regeneration	75-200
85	Chlorination	25-75
86	Equalization	25-75
87	Ion Exchange	200-500
88	Liquid Ion Exchange	200-500
89	Precipitation/Floc Sedimentation	40-100
90	Pure Oxygen Activated Sludge	75-400
91	Rotating Biological Disc and Clarifier	75-500
92	Trickling Filter	75-200
93	Wet Air Oxidation	40-100

3.4 GROUNDWATER

3.4.10 Leachate Attenuation

Description: Subsurface drain system as discussed in 2.4.3 and 3.4.3 with additional pumps and recharge areas for leachate discharge. Recharge basin.

Multipliers: Same as for 3.4.3. Unit costs given due to site specific nature of activity.

COSTS

ID#	DESCRIPTION OF ACTIVITY	$COSTS/UNIT (L.YD.)
	Subsurface Drains*	228.82-322.60
1	Unclassified Excavation (recharge area) See Section 3.3.7 - Sedimentation Ponds and Basins for further discussion	2.00- 4.50/yd^3

*Drain necessary to collect leachate. Distribution system to carry leachate to recharge area consists of pipes and pump already costed out in 3.4.3. Site specific nature of amount of leachate, area necessary for recharge and amount, type, and design of pumps precludes further derivation of units costs.

3.4 GROUNDWATER

3.4.11 Groundwater Monitoring

Description: Well casing of 4" diameter. Well screen = 10 ft. with 15 feet of drain rock 3/4" min. surrounding bottom portion of well. drilled hole ≐ 8"-12" in dia.

Multipliers: Volume of drilled hole/vertical yd. = .09 yd^3/yd
Volume of well/vertical yd. = .01 yd^3/yd
Volume of drilled hole outside of well = .08 yd^3/yd

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTIPLIER	$/COST/UNIT
63	Wells drilled up to 24" dia.	15.00/ft	3 ft/yd	$ 45.00/yd
65	6" PVC Casing	4.50/ft	3 ft/yd	$ 13.50/yd
20	Backfill - casing	.75/yd^3	.08 yd^3/yd	$ .06/yd
68	Well screen - 4" x 10ft.	15.00/ft	10 ft.	$150.00 lump sum
7	Drain rock - 15 ft.	9.50/yd^3	.08 yd^3/yd· ·5 yds.	$ 38.00 lump sum
67	Concrete cap	250.00 ea. well		$250.00 ea.
70	Concrete seals and equipment	250.00 ea. well		$250.00 ea.
56	Submersible pump	1,175.00 ea.		$1,175.00

Total Costs

Well Construction	$58.56/yd
9% Engineering and 15% Contingency	14.84
	$73.40/yd

Add to total

Well screen and assorted equipment and fill	$1,863.00
9% Engineering and 15% Contingency	472.25
	$2,335.25

Total Cost for Well = $73.40/vertical yard + $2,335/well

3.5 DISEASE

Unit cost estimates for reducing or eliminating the potential for disease from landfills could not be determined. The wide variance in possible existing situations makes derivation of general costs impractical. Control of Disease is usually a function of proper daily operating procedures and not intense construction technologies. Furthermore, the many different and distinct combinations of site characteristics and possible disease would make a general cost estimate practically useless for site operations. If disease is suspected to be a problem, local and state health officials should be notified immediately.

3.6 AIR

Derivation of unit costs for controlling adverse impact of landfills on air quality were not derived. Control of air pollution from landfills are more a function of proper daily operating procedures than construction of remedial technologies. In addition, the wide variation in types of sites and the possibilities which might exist in various regions of the country make general unit costs impractical since they would have no bearing on what cost could be expected at specific sites.

3.7 SAFETY

3.7.1 Gases - Assessing Potential Gas Hazard

Description: Soil Samples, Test wells and analysis

Multipliers: not applicable

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$COST/UNIT
94	Soil Testing (per sample) 10 samples/acre	2160.00/acre
95	Hydrometer analysis and specific gravity	60.00 ea.
96	Seive Analysis, washed	8.00 ea.
	unwashed	50.00 ea.
97	Moisture Content	8.00 ea.
98	Permeability	50.00 ea.
99	Proctor Compaction	40.00 ea.
69	Test Wells - Gas probe included along with pressure measurement and 3 test wells/acre of at least 20 ft. depth.	20.00-28.00/ft.

TOTAL COSTS

Soil Testing complete series 10/acre	$2,160.00/acre
3 Test wells of 20ft. depth	1,200.00-1,680.00
	$3,360.00-3,840.00
add 9% engineering cost	302.40- 345.60
	$3,662.40-4,185.60
add 15% contingency cost	549.60- 627.20
estimated cost for gas monitoring	$4,212.00-4,712.80/acre

3.7 SAFETY

3.7.1 Gases - Active Control Systems

Description: perforated pipe in gravel filled well up to 20 ft connected by manifold pipe control exhaust pump
alternative: pipe in gravel filled trench to control capability of trench system to collect gas.

Multipliers: Volume of well = 24" dia. = $1.4yd^3/yd$
volume surrounding pipe = $1.38yd^3/yd$
volume of pipe = 6" dia. = $.02yd^3/yd$

CONSTRUCTION COSTS - Pipes in wells to manifold for disposal

ID#	DESCRIPTION OF ACTIVITIES	$/UNIT	$COST/UNIT
63	Well - depth 24" dia	15.00/ft 20ft.	$300.00/well
8	Gravel - run of the bank	$\$6.00/yd^3 x 1.38yd^3 x 6.67yd^3/20ft$	55.25/well
104	Cement plug and anchor	25.00 each	25.00/well
46	PVC pipe class 160 perforated	2.25-6.00/ft. 20ft.	45.00-120.00/well
70	Concrete seals and test equipment	250.00/well	250.00/well
	MANIFOLD SYSTEM		
60	Header pipe 8"	46.00/foot	
71	500-2000 CFM 8" H_2O Fan	1,900.00-2,050.00 each	
70	Concrete seals and test Equipment	250.00/fan or outlet	

TOTAL COSTS

Well construction	$425.25-$500.25/well
Manifold connections	46.00/ft. of manifold
Equipment	$2,150.00-2,300/fan or outlet

3.7 SAFETY

3.7.1 Gases - Passive Liner Systems

Description: Costs for liners are derived in Section 3.3.7 and 3.3.8 and need not be discussed further.

3.7 SAFETY

3.7.1 Gases - Collection/Removal/Venting Systems

Description: Passive control strategies - Gravel trenches
Trenches of 20 ft. deep by 6 ft. wide, lined with PVC membrane. Costs for additional venting are provided.

Multipliers: Volume of trench/yard = 13.34yd^3/yd
Area of bottom and side/yd = 8.67
Vent pipe - 10 feet

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COST/UNIT(1.yd.)
15	Trench Excavation 0-25ft.	15.50-25.00/yd^3	13.34	206.75-333.50
6	Borrow-Run of the Bank Gravel	6.00/yd^3	13.34	80.00
39	20 mil., PVC Membrane	1.30-2.00/yd^2	8.67	11.25- 17.35
				298.00-430.85
	WITH VENTING PIPES			
46	PVC pipe class 160	2.00-6.00/ft		6.00-18.00/yd
105	Cement plug	$25.00 each		5.00/yd

TOTAL COSTS	$/YD
Trench Construction	$298.00-430.85
Venting pipe and plug	11.00- 22.00
	$309.00-452.85
9% engineering cost	27.00- 40.00
	$336.00-492.85
15% contingency cost	50.00- 73.15
	$386.00-566.00

Cost of collection trench/yd = $386.00-566.00

3.7 SAFETY

3.7.1 Gases - Venting and Disposal of Collected Gas

Description: venting and disposal costs for 1 disposal operation of 500-2000 CFM range

Multipliers: Not applicable

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT
109	Non-regenerative Carbon adsorption system treating vent gas 2000 CFM	minimum $35,000.00 installed including site work.
110	Regeneration Carbon absorption system treating vent gas 2000 CFM	minimum $140,000.00 installed including site work.
111	Small ground flares 2000 CFM	minimum $25,000.00 installed including distribution, anti-blowbank, and re-igniter, and pressure maintenance system.
112	Landfill gas recovery installed costs for 1 million ft^3/day	$450,000.00-$795,000.00

3.7 SAFETY

3.7.2 Fires - No unit costs can derived for fire control. Equipment needs and daily operating practices are too varied to allow analysis of unit costs.

3.7 SAFETY

3.7.3 Bird Hazards

Description: unit charges for tripshot method not available.
Cost for wire canopy over 1 acre included.

Mulitpliers: 10 rows 20 feet apart support at ½ of intersection.
# of supports = 62
length of wire = 30240 ft.
anchor - 1' x 1' x 3' = .11 c.y.

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	MULTI-PLIER	$COST/UNIT
104	Concrete anchor	25.00 each	62	$1,550.00
113	Support posts 3" dia.- 15" high	25.50/post	62 posts	1581 acre
	Wire rope 1/2"	.75/ft.	30,240 ft.	22,680.00
				25,811.00

TOTAL COSTS/acre

	$25,811.00
9% Engineering	2,323.00
	$28,134.00
15% Contingency	4,220.00
	$32,354.00 acre

3.7 SAFETY

3.7.4 Access

Description: Chain Link fence 6' high topped with 3 strands Barbed wire, 2" line post @ 10' o.c. 1 5/8" top rail. Unit costs/yd cannot be determined due to site specific nature of technology.

Multipliers: not applicable

CONSTRUCTION COSTS

ID#	DESCRIPTION OF ACTIVITY	$/UNIT	$COST/UNIT
75	6 ga. galvanized steel wire link	$10.25/ft.	30.75/yd.
76	corner posts 3" diameter	$100.00 each	100.00 each
125	Braces - steel	25.00 each	25.00 each
77	sliding gate 45' long	2,050.00/pair	2,050.00/pair
	concrete anchors	$450.00 each corner or gate	

4.0 COMPARISON OF CONTROL ALTERNATIVES

Comparison of the control technologies and their associated costs are provided here as a summing of the information covered in Chapters 2.0 and 3.0.

Table 4-1 discusses by criterion, each control technology option, where each technology is applicable, and the gross capital cost on a unit basis for constructing the technology. This table is supported by the detailed discussion of Chapters 2.0 and 3.0, Control Technologies and Cost of Upgrading.

TABLE 4-1 Alternative Landfill Technologies

CRITERION	CORRELATE	REMEDIAL ACTION ALTERNATIVES	APPLICABILITY	UNIT CAPITAL COST*
Floodplains	4.1.1	Berms	Protecting landfills from floods, refuse	$229.67 - 342.67/yd
		Dikes	Placed on inboard side	
		Levees	Best where good source of clay	
	4.1.2	Floodwalls	Need to maximize refuse capacity	350.75 - 604.00/yd
	4.1.3	Control Backwater Flow	Where normal flow has been inhibited	$7,000.00 - 30,000 Total
Endangered Species	4.2.1	Protecting Endangered Species	Where proper habitat can be provided to co-in site	Not possible to determine
	4.2.2	Selective landfilling	Protecting wildlife providing enhanced habitat	Not possible to determine
	4.2.3	Mitigation Land	Compensation for disposal land-availability of adjacent lands	Not possible to determine
	4.2.4	Vertical Landfilling	Low water table, good supporting soil	Not possible to determine
Surface Water	4.3.1	Ditches	Diverting off-site water from site	14.66 - 20.20/yd
		Diversions	o used above and below disturbed areas - temp.	
			o permanent or temporary along contours or slope	
		Waterways	o stabilized with vegetation	
	4.3.2	Terraces	Constructed along contour of slope	5.48 - 8.13/yd
		Benches	Slope reduced devices, isolate disposal site and control erosion	
	4.3.3	Chutes	Carry runoff - permanent concrete	5.03 - 8.40/yd
		Down-Drains	o temporary pipes	85.00 - 86.26/yd
	4.3.4	Drainage Systems	Remove specific volume of water in a certain amount of time	40.50 - 628.00/yd
	4.3.5	Surface Grading and Planting	Intercept runoff and infiltration, enhance runoff and minimize erosion	2.50 - 7.50/yd^2
	4.3.6	Surface Capping	Prevent or minimize leachate production	11.00 - 30.00/yd^2
	4.3.7	Sedimentation Ponds	Settle out silt in leachate	8,000.00-11,000.00/acre ft.
	4.3.8	Liners	Contain leachate and prevent contamination with groundwater	27,000.00-70,000.00/acre
	4.3.9	Control of Leachate Seepage	Where leachate cannot be prevented from forming	

* cost without engineering or contingency costs.

TABLE 4-1 cont'd.

CRITERION	CORRELATE	REMEDIAL ACTION ALTERNATIVES	APPLICABILITY	COSTS
Groundwater	4.4.1	Trenches	Depth at low-permeability costs ia shallow	290.00 - 4500.00/yd
	4.4.2	Grouting	Areas of permeable soil/rock and voids	6,000.00 - 11,000/yd
	4.4.3	Subsurface Drains and Dewatering system	Lower water table and/or collect leachate	
		Subsurface Drains	o collect leachate	528.00 - 700.00/yd
		Extraction Wells	o collect leachate and/or depresa groundwater level	24.00 - 40.00/vertical ft.
		Well Point Systems	o plane and leachate contamination	50.00 - 100.00/yd
	4.4.4	Leachate Collection Facilities	Remove leachate from landfill	25.00 - 30.00/yd
	4.4.5	Leachate Treatment	Treatment of collected leachate	20,000.00 - 500,000 total
	4.4.6	On-Site Treatment	On-site leachate treatment, if facilities available	
	4.4.7	Discharge Treated Leachate	Discharge after treatment if land available	
	4.4.8	Leachate Treatability	Identify degree of treatability	
	4.4.9	Leachate Recirculation	Accelerate biostabilization by recirculation	
	4.4.10	Leachate Attenuation	Attenuation of hydrogeology to abate degradation	230.00 - 325.00/yd
	4.4.11	Groundwater Monitoring	All sitea which are not currently monitoring groundwater	75.00/vertical yd + 2,500/well
Disease	4.5.1	Sewage Sludge - Septic Tank Pumping	All aites which apread aludge & pumpinga	
	4.5.2	Controlling Vectors	All sites with vector problems	
	4.5.3	Controlling Rodents	All sites with rodent problems	
	4.5.4	Controlling mosquitos	All aitea with mosquito problems	
	4.5.5	Controlling Health Hazards	All sites with health hazard problems	

TABLE 4-1 cont'd.

CRITERION	CORRELATE	REMEDIAL ACTION ALTERNATIVES	APPLICABILITY	COSTS
Air	4.6.1	Controlling Fires	All sites with fire potential	
	4.6.2	Controlling Dust	All sites with dust problem	
Safety	4.7.1	Gases	All sites with methane production	
		Liners	Sites which cannot other wise collect gas	See 5.3.7 - 5.3.8
		Vents	Where gas can be collected and vented	386.00 - 566.00/yd
		Wells Probe	Methane detection	4,212.00 - 4,712.00/acre
	4.7.2	Fires	All sites with fire hazards	
	4.7.3	Birds	All sites with bird problems	32,354.00/acre
	4.7.4	Access	All sites with open access cable canopy	30.75/yd plus 2,250.00

END

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